Gilhervach
Mar 26, 1951

INTERNATIONAL GEOLOGICAL CONGRESS

REPORT OF THE EIGHTEENTH SESSION
GREAT BRITAIN 1948

PART VI ⑥

PROCEEDINGS OF SECTION E

THE GEOLOGY OF PETROLEUM

LONDON
1950

INTERNATIONAL GEOLOGICAL CONGRESS

REPORT OF THE EIGHTEENTH SESSION
GREAT BRITAIN 1948

General Editor: A. J. Butler

PART VI

PROCEEDINGS OF SECTION E

THE GEOLOGY OF PETROLEUM

Edited by
G. D. HOBSON

LONDON
1950

Section E, The Geology of Petroleum, met on three occasions during the Session. The successive Chairmen at these meetings were as follows :—

August 26th	Professor V. C. Illing
	Mr. P. Evans
August 27th	Professor V. C. Illing
	Dr. G. M. Lees
August 31st	Professor V. C. Illing
	Dr. H. G. Kugler
	Mr. A. R. Denison

The Secretary of the Section was Dr. G. D. Hobson

Contents

* A joint discussion which followed the presentation of these six papers is reported on page 68.

QUELQUES CONSIDÉRATIONS SUR LES GISEMENTS DE PÉTROLE DU SUD DE LA FRANCE

Par L. BARRABÉ

France

ABSTRACT

Après un rappel sommaire des conditions dans lesquelles les recherches de pétrole, qui ont conduit à la découverte des importants gisements de gaz de Saint Marcet, ont été entreprises, les résultats essentiels des recherches en cours effectuées dans l'Aquitaine, les Petites Pyrénées et la Languedoc sont exposées brièvement. La nature et l'âge des roches mères possibles est ensuite discutée. Enfin les résultats scientifiques généraux obtenus grâce aux études géologiques et géophysiques, ainsi qu'aux données des forages (variations de faciès, nouvelles structures dans l'Aquitaine, grande faille de Lunel-Nîmes) sont mis en évidence, permettant de mieux comprendre la structure de la région qui s'étend entre le domaine des gisements pyrénéo-provençaux au Sud et le domaine des massifs hercyniens surélevés au Nord.

LA prospection du pétrole en France n'a été organisée méthodiquement qu'à partir de 1923, par l'Etat et sous la direction de l'Office National des Combustibles Liquides (O.N.C.L.). Les premières recherches effectuées sur mes directives, confirmées par P. Viennot, ont abouti à la découverte dès le premier forage, en 1924, du petit gisement pétrolifère de Gabian (Hérault), qui a produit au total, depuis cette date, près de 30,000 tonnes d'huile. Malgré ce premier succès, les recherches en France furent quelque peu délaissées pendant une dizaine d'années, au cours desquelles les efforts de l'O.N.C.L. se portèrent presque exclusivement sur la prospection des Colonies. Seules quelques sociétés privées ne disposant que de moyens réduits, poursuivirent une campagne de forages, notamment dans le Béarn et les Landes (Nord des Pyrénées occidentales), où de nombreux indices d'hydrocarbures étaient connus depuis longtemps. Aucun résultat positif ne fut obtenu.

Cependant la bordure septentrionale des Pyrénées présentait, du point de vue théorique, des conditions très favorables à la constitution de gisements de pétrole, mais plus particulièrement dans les Petites-Pyrénées en avant des Pyrénées Centrales, malgré l'absence de tout indice connu alors dans cette dernière région. C'est en nous basant sur ces considérations que Léon Bertrand, Pierre Viennot et moi-même, avions préconisé, dès 1925, la prospection par forage des Petites Pyrénées de Saint-Gaudens. Ce n'est qu'en 1936 que l'O.N.C.L. se rallia enfin à notre proposition, chargeant M. Ch. Jacob, Léon Bertrand, M. D. Schneegans et moi-même de la direction scientifique des recherches.

C'est alors, en 1937, que j'ai présenté, en collaboration avec mon regretté maître Léon Bertrand, au 2ème Congrès Mondial du Pétrole, en juin 1937, une note " sur l'existence, le long du bord septentrional des Pyrénées, d'une avant-fosse de chaîne plissée, telle que celles qui ont donné naissance à de nombreux gîtes pétrolifères classiques." Je ne reprendrai pas ici les arguments développés dans cette communication à laquelle M. le Professeur Macovei fait allusion dans son traité sur la Géologie du Pétrole, concluant que le résultat des recherches entreprises décidera seul de la valeur de notre hypothèse. La réponse ne s'est pas fait longtemps attendre puisque, dès juin 1939, le premier forage exécuté près de Saint-Marcet a atteint, a 1,530 m. de profondeur, un important gisement de gaz renfermant environ 82% de méthane et 18% d'homologues supérieurs, sous une pression correspondant à près de 150 kg. à la surface du sol. Quelques semaines plus tard, le même forage rencontrait à 1,835 m. un niveau pétrolifère donnant une huile légère paraffineuse. Toutefois, un accident technique empêcha les essais de production, et ce n'est que tout récemment que le puits a pu être repris, fournissant aux essais environ 15 tonnes de pétrole par jour.
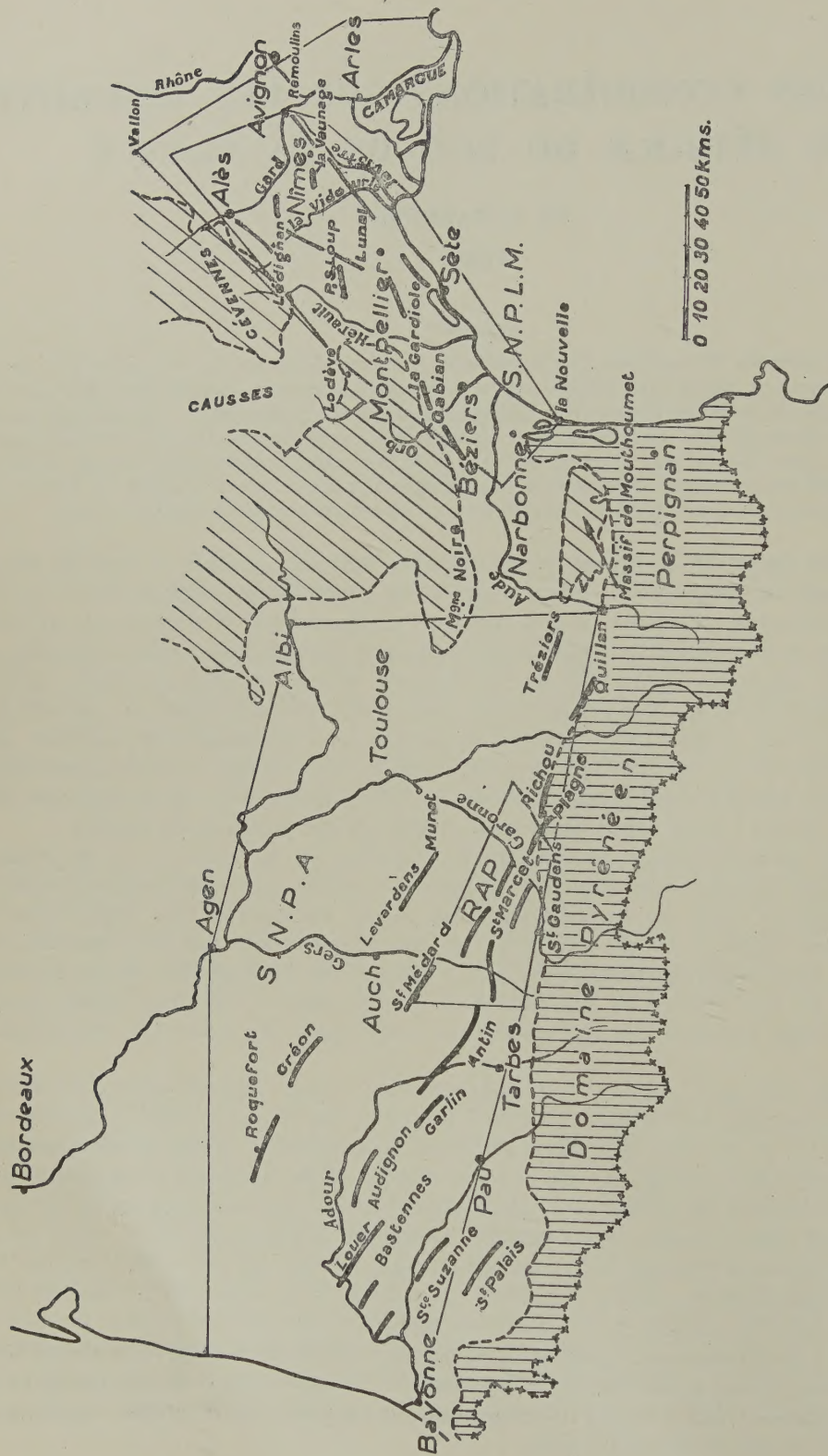
Fig. 1.—*Schéma structural de l'Aquitaine méridionale et du Languedoc.*

Les hachures verticales indiquent la zone des plissements intenses des Pyrénées; les hachures obliques marquent les massifs hercyniens de l'avant-pays.

Parallèlement à la prospection des Petites-Pyrénées, d'autres recherches avaient été entreprises par l'O.N.C.L. dans le Languedoc, mais celles-ci, faute de matériel de forage, durent être interrompues en 1939. A la suite de la découverte du gisement de gaz de Saint-Marcet, la prospection est entrée progressivement dans une phase active dans tout le midi de la France, depuis l'Atlantique jusqu'à l'Aude, où les travaux sont confiés à la Société Nationale des Pétroles de l'Aquitaine (S.N.P.A.), disposant ainsi d'un périmètre qui encadre celui de la Régie Autonome des Pétroles (R.A.P.) représentant l'Etat, puis de la basse vallée de l'Aude au Rhône, où la Société Nationale des Pétroles du Languedoc Méditerranéen (S.N.P.L.M.) a entrepris des recherches basées sur la présence de nombreuses manifestations d'hydrocarbures, ainsi que du petit gisement de Gabian.

CARACTÈRES STRUCTURAUX DE LA RÉGION EXPLORÉE

Cette longue bande de terrain en cours de prospection s'étend ainsi de l'Océan à la vallée du Rhône, sur 500 km., avec seulement une interruption de moins de 50 km. au Sud de la Montagne-Noire. Au point de vue géologique, c'est l'avant-pays septentrional de la chaîne pyrénéo-provençale, si l'on admet l'hypothèse adoptée par beaucoup de géologues, de la prolongation des Pyrénées, au-delà du Golfe du Lion, par les chaînes provençales des Maures avec leur cadre plissé mésozoïque. Il faut cependant remarquer que les caractères stratigraphiques et tectoniques de cette région sont très variés d'une extrémité à l'autre de ce bassin, du fait à la fois de l'éloignement plus ou moins grand de la chaîne pyrénéo-provençale et de la distance à laquelle se trouvait aux diverses époques géologiques le massif hercynien émergé de l'avant-pays. Pendant presque toute la durée des temps secondaires, le Massif Central s'avançait jusqu'aux abords des Pyrénées Orientales, et ce n'est qu'à la fin du Crétacé que le Massif de Monthoumet s'est trouvé séparé de la Montagne-Noire par un ennoyage correspondant à la basse vallée actuelle de l'Aude.

Le bassin d'Aquitaine, qui s'ouvre largement à l'Ouest de cette ancienne avancée du Massif Central, a eu une histoire stratigraphique bien différente de celle du bassin oriental du Languedoc méditerranéen, beaucoup plus étroit, et qui ne s'élargit qu'à partir du Gard pour aller confluer avec le bassin rhodanien. Il semble toutefois que dans le bassin d'Aquitaine, un seuil surélevé ait prolongé l'extrémité SW du Massif Central jusqu'aux abords de la côte atlantique actuelle, parallèlement aux Pyrénées, pendant une grande partie du Secondaire, séparant ainsi plus ou moins complètement une fosse sous-pyrénéenne du bassin Nord-Aquitain. Pendant le début du Secondaire et jusqu'à la fin de l'Albien, la zone nord-pyrénéenne était occupée par un sillon de subsidence, sauf probablement entre le Bathonien et l'Aptien, période qui est marquée par une lacune stratigraphique, bien qu'aucune phase orogénique notable n'ait eu lieu à cette époque en dehors des Pyrénées occidentales. Ce sillon se prolongeait vers le Nord par une mer épicontinentale qui occupait le Sud du Bassin d'Aquitaine.

A la fin de l'Albien, une phase orogénique importante a entraîné le plissement et l'émersion de presque toute la zone nord-pyrénéenne; la mer a été alors rejetée dans l'avant-pays, et une nouvelle fosse de subsidence ou *avant-fosse*, s'est constituée au Nord de la chaîne qui venait de surgir. Ce nouveau sillon a été remblayé surtout par d'épais dépôts du Crétacé supérieur, présentant le plus souvent un faciès de flysch, tandis qu'au nord, vers le centre du Bassin d'Aquitaine, les formations sédimentaires de même âge étaient réduites et à caractère franchement néritique.

Une dernière phase orogénique intense a eu lieu à la fin de l'Eocène, à partir du Lutétien moyen, donnant naissance aux Pyrénées actuelles et affectant de plis modérés l'avant-pays aquitain, et plus particulièrement le remplissage de l'avant-fosse. Ces plis sont surtout bien visibles entre l'Aude et le plateau du Lannemezan, à l'Ouest de la Garonne; ce sont les Petites Pyrénées.

Dans le *Languedoc méditerranéen*, au-delà de l'éperon primaire du Massif de Monthoumet, qui n'a été séparé par un bras de mer du Massif Central qu'au cours de l'Eocène, la sédimentation a présenté au cours du Secondaire, des caractères entièrement différents de ceux observés dans le Sud du Bassin d'Aquitaine.

Dans le *Languedoc occidental*, à l'Est d'un seuil jurassique qui prolonge les Causses jusqu'à la Mer Méditerranée, entre l'Orb et Montpellier, et sur lequel ne subsistent plus d'autres dépôts crétacés que le Danien lacustre, la série stratigraphique rappelle celle de la bordure Nord des Pyrénées, mais avec des faciès néritiques qui s'expliquent par le voisinage de l'éperon paléozoïque Montagne Noire—Massif de Monthoumet.

Les formations mésozoïques et éocènes de cette région sont affectées de chevauchements et d'écailles poussées vers le NW sur le massif ancien. Ce style tectonique se poursuit sur toute la bordure méridionale de la Montagne Noire, mais en s'atténuant vers l'Est.

Le seuil jurassique situé à l'Est de l'Orb présente des plis transversaux, à direction moyenne SW—NE, qui ont une tendance de plus en plus accusée, vers le Nord (c'est-à-dire vers le détroit des Causses, entre la Montagne Noire et les Cévennes), à se déverser et même à chevaucher vers le Nord.

Au-delà de ce seuil, parfois désigné sous le nom *d'éperon jurassique*, vers l'Est, le Languedoc oriental est caractérisé par le développement du Crétacé inférieur qui n'existe plus à l'Ouest. C'est l'extension vers le SW de la fosse vocontienne qui s'étendait entre les Alpes et le Massif Central. Contrairement à ce qui s'observe dans les Pyrénées—Aquitaine et dans le Languedoc occidental, la sédimentation est continue ici depuis le début du Jurassique jusqu'au Crétacé moyen. Ce dernier, par contre, est localement très réduit, ou même absent, sur un haut-fond, ou "*isthme durancien*," situé au Nord du Delta du Rhône.

Le Languedoc oriental est caractérisé par une tectonique comportant des plis atténués, avec larges dômes, affectant toutes les formations ante-oligocènes, et de longues failles en majeure partie post-oligocènes, mais qui ont dû exister déjà dès la fin de l'Eocène, jouant ainsi un rôle important dans la formation du bassin oligocène d'Alès, qui s'étend avec une direction SW—NE, entre les Cévennes et le Rhône.

Des dépôts néogènes et quaternaires recouvrent largement certaines parties du bassin du Languedoc, rendant difficile l'étude des structures du substratum plissé. Le Miocène a été souvent affecté d'une manière appréciable par les derniers plissements alpins.

RÉSULTATS PRATIQUES

Les recherches entreprises dans le Sud de l'Aquitaine et dans le Languedoc méditerranéen sont trop peu avancées pour qu'il soit possible de prévoir dès maintenant l'importance que pourront prendre ces régions au point de vue de la production des hydrocarbures. Cependant un bilan sommaire des résultats déjà acquis à l'heure actuelle permet de préjuger favorablement de la suite des prospections en cours.

La R.A.P. a découvert et exploite le gisement de Saint-Marcet, qui produit journellement en moyenne 500,000 m3 de gaz renfermant, outre du méthane, une forte proportion d'homologues supérieurs (11%) fournissant environ 20 tonnes d'essence par condensation. Ce gisement, qui est un des plus gros producteurs d'Europe, produit en outre 15 à 20 tonnes d'huile paraffineuse par jour.

L'exploration des anticlinaux des Petites-Pyrénées n'a pas encore permis la découverte de nouveaux gisements exploitables; cependant, l'anticlinal de Plagnes, qui relaie vers l'Est, au-delà de la Garonne, le pli de Saint-Marcet—Saint-Martory, paraît mériter une prospection systématique par forages. Celle-ci n'a été en effet qu'à peine ébauchée, car trois sondages seulement ont été effectués jusqu'ici sur cette vaste structure, longue de près de 20 km. et large de 5 km. en moyenne. Le premier de ces sondages, que des difficultés techniques n'ont pas permis de poursuivre, a atteint, à 1,880 m., à la base du Flysch crétacé supérieur, des brèches qui ont fourni une venue de gaz sous forte pression, avec un peu d'huile et d'eau salée. Un quatrième forage vient d'être entrepris au voisinage du précédent pour vérifier l'existence d'un gisement exploitable dans cette structure. Malgré quelques échecs sur les autres anticlinaux des Petites Pyrénées (imprégnations de pétrole non saturant dans des grès du Flysch de la structure de Gensac, indices d'huile et d'eau salée dans les dolomies jurassiques de la structure de Puymaurin, au NW de Saint-Marcet), rien ne permet encore d'en déduire l'absence de gisements.

La S.N.P.A. n'a pu encore découvrir aucun gisement exploitable; cependant dans l'anticlinal d'Audignon, au Sud de Mont-de-Marsan (Landes), un forage a produit 12,000 litres d'huile lourde, dans le Lias, à 3,520 m. En outre, divers indices intéressants ont été rencontrés dans d'autres structures: dans différents niveaux (Crétacé supérieur, Albien et Trias) de l'anticlinal de Garlin, au Nord de Pau; dans le noyau triasique de l'anticlinal de Saint-Médard, au Sud d'Auch, &c. . . .

La prolongation des plis des Petites-Pyrénées a été aussi explorée vers l'est, mais jusqu'ici, seul un ancien forage effectué sur l'anticlinal de Dreuihl, entre l'Ariège et l'Aude, a rencontré quelques indices (gaz combustible).

Les régions plus septentrionales de l'Aquitaine n'ont encore fourni aucun indice intéressant, mais elles n'ont encore fait l'objet que de recherches très limitées.

Dans le Languedoc, la S.N.P.L.M. n'exploite que le petit gisement de Gabian qui ne fournit plus que quelques centaines de litres par jour. Par contre, les recherches entreprises par cette société, ont mis en évidence des indices importants. D'anciens forages effectués par l'Etat avaient déjà révélé des imprégnations d'huile dans le Jurassique supérieur de l'anticlinal de Castelnau-de-Guers, près de Pézenas, au Sud de Gabian, et dans du Lias subvertical, au-dessous d'une surface de chevauchement dans le dôme faillé du Pic Saint-Loup, au Nord de Montpellier. C'est toutefois l'existence d'une accumulation, sous très forte pression, de gaz (constitués par des hydrocarbures associés à une forte proportion, près de 50% d'anhydride carbonique) à la base du Jurassique supérieur, dans le brachy-anticlinal de la Vaunage, à l'Ouest de Nîmes, qui présente jusqu'ici le plus d'intérêt pour l'avenir. Les essais de production n'ont toutefois pas encore été faits, et aucune certitude n'existe encore sur la présence d'un gisement d'hydrocarbures exploitable dans ce dôme. Enfin, un forage implanté sur un compartiment surélevé du Bassin oligocène d'Alès, a mis en évidence une accumulation de gaz comportant aussi des hydrocarbures et de l'anhydride carbonique, dans des calcaires stampiens.

En résumé, aucun gisement d'hydrocarbure exploitable n'a encore été découvert en dehors de celui de Gabian, qui est presque épuisé, et de celui de Saint-Marcet, qui est l'un des premiers producteurs de gaz d'Europe; cependant, bien des faits nouveaux permettent d'espérer à brève échéance la découverte de nappes productives de gaz ou de pétrole dans certaines structures en cours d'exploitation, notamment dans celles d'Audignon, de Plagnes et de la Vaunage.

RÉSULTATS THÉORIQUES

Ce sont essentiellement les résultats des recherches en cours au point de vue théorique qui m'ont paru mériter d'être exposés devant le Congrès.

(a) *Roches-mères.*—La détermination des *roches-mères* ayant contribué à la constitution des gîtes de pétrole, est un problème difficile et qui, probablement pour cette raison, paraît être laissé actuellement à l'arrière-plan des préoccupations des géologues pétroliers. Il semble cependant qu'à moins d'admettre une origine éruptive à laquelle plus personne ne croit, le problème de l'identification des *roches-mères* ne doit pas être perdu de vue. Il faut seulement tenir compte du fait que bien des roches renfermant, ou ayant renfermé des matières organiques, peuvent avoir joué un rôle dans la formation des pétroles, et qu'il n'est pas possible de limiter à quelques types bien définis les roches-mères probables. Il ne faut pas non plus négliger la possibilité de migrations latérales très étendues, qui permettent d'expliquer la présence de gisements, d'hydrocarbures importants, loin des zones où sont localisées les roches-mères possibles. Mais, tout en tenant compte de ces remarques, la recherche des formations sédimentaires qui ont pu jouer le rôle essentiel dans la genèse des pétroles, pour une région donnée, ne saurait être considérée comme dépourvue d'intérêt.

J'ai déjà examiné ce problème, en ce qui concerne l'Aquitaine et le Languedoc, dans une communication au Congrès de l'Association Française pour l'Avancement des Sciences, à Paris, en 1945, mais cette note n'est pas encore publiée.* Depuis lors, des données nouvelles ont été apportées par les

---

* Le problème des roches-mères du pétrole en Aquitaine et en Languedoc. Association Française pour l'Avancement des Sciences—Congrès de la Victoire. Paris 1945, 3, pp. 25–30.

recherches en cours. En tenant compte de toutes les observations réunies jusqu'ici, on peut donner le tableau suivant des roches-mères qui ont pu contribuer à la formation des hydrocarbures déjà reconnus dans la bordure nord des chaînes pyrénéo-provençales, à l'Ouest du Rhône.

(1) Les formations de *base de l'Oligocène*, et peut-être l'Eocène supérieur du bassin d'Alès et du bassin hypothétique de la Vistre (bordant au Sud la faille de Nîmes), ont pu jouer un rôle essentiel dans la formation des hydrocarbures qui se rencontrent dans l'Oligocène supérieur (Stampien), ou dans les marnes ou les calcaires du Crétacé inférieur en contact par faille avec l'Oligocène.

(2) Le *Flysch crétacé supérieur* de l'avant-fosse pyrénéenne, flysch auquel le rôle de roche-mère a été attribué par beaucoup de géologues, ne peut plus être considéré comme la seule formation susceptible d'avoir fourni les hydrocarbures du bassin sud-aquitain. En effet, si bien des indices de pétrole reconnus depuis longtemps dans des horizons plus anciens que le Crétacé supérieur, pouvaient s'expliquer par des migrations latérales à partir du Flysch, par contre, la petite production d'huile qui a été obtenue dans un forage effectué dans le flanc nord de l'anticlinal d'Audignon, à 2,180 m., dans l'Infra-Lias, sous l'axe triasique déversé du pli, après avoir traversé près de 2,000 m. de Crétacé moyen, ne saurait provenir du Crétacé supérieur qui, au surplus, ne présente plus ici qu'une épaisseur réduite et un faciès épicontinental.

Le rôle du Flysch dans la formation des hydrocarbures de l'Aquitaine ne peut pas toutefois être rejeté entièrement de ce fait, car les indices qui s'y rencontrent sont nombreux et ils ne sont pas tous localisés, comme on l'a parfois affirmé, aux abords des noyaux diapirs de Keuper. Par contre, en dehors du Danien à faciès lacustre, le Crétacé supérieur manque dans presque tout le Languedoc (à l'exception du Narbonnais où il a un faciès surtout détritique), et n'intervient donc pas dans la constitution des pétroles de cette région.

(3) Le *Crétacé moyen* (Albien et Aptien) qui présente aussi souvent un faciès flysch marno-gréseux ou marno-calcaire, peut avoir contribué à la formation d'hydrocarbures, bien que l'épaisseur de cette formation paraisse souvent réduite dans l'avant-fosse pyrénéenne où se rencontrent les seuls gisements reconnus. Ces niveaux manquent dans le Languedoc, sauf dans le Narbonnais d'une part, et le bassin rhodanien d'autre part, où leur faciès est un grande partie subrécifal.

(4) Le *Crétacé inférieur* par contre, manque entièrement dans le bassin d'Aquitaine et dans le Languedoc occidental, tandis qu'il est largement développé dans le Languedoc oriental, où il est très épais, avec un faciès marin marno-calcaire qui devient franchement bathyal dans la fosse vocontienne entre le Rhône et les Alpes. La présence d'hydrocarbures gazeux dans le Crétacé inférieur de la Vaunage, au-dessus des marnes valanginiennes imperméables peut faire admettre que le Crétacé supérieur a pu jouer ici le rôle de roche-mère, mais il ne semble pas qu'il ait donné naissance à d'importants gisements.

(5) Le *Jurassique moyen* comporte dans la plus grande partie des régions prépyrénéennes et dans la partie orientale du Languedoc, des dolomies sombres, fétides, renfermant une faible proportion d'hydrocarbures; toutefois, si ces roches peuvent jouer le rôle de roche-magasin, il est peu vraisemblable qu'elles aient donné naissance à de grandes quantités de pétrole.

(6) Les *marnes du Lias supérieur* sont souvent riches en matières organiques et passent localement à des schistes bitumineux qui sont exploités dans les Causses. Il a donc paru naturel d'y voir la source des hydrocarbures qui imprègnent les dolomies du Jurassique moyen, mais c'est surtout dans le Languedoc oriental que ces marnes ont un caractère de schistes bitumineux (pyro-bitumes); dans l'avant-pays pyrénéen, elles semblent n'avoir pu jouer qu'un rôle plus réduit.

(7) Les *schistes noirs autuniens* de la bordure sud du Massif Central sont aussi riches en matières organiques et comportent localement des schistes bitumineux. Ce sont souvent des formations lacustres dont le rôle dans la formation de pétrole pourrait paraître peu probable; toutefois, leur faciès devient parfois lagunaire, et il est vraisemblable dès lors qu'ils sont à l'origine de la plus grande partie des pétroles du Languedoc. La mise en évidence, par des forages, d'un Permien lagunaire puissant

s'étendant largement sous le Languedoc méditerranéen, serait cependant indispensable pour confirmer cette hypothèse. Aucune donnée géologique de surface ne permet, par contre, d'étendre cette conception à l'avant-pays pyrénéen: l'Autunien n'est connu que dans le Bassin de Brive, dans le NE de l'Aquitaine, tandis que dans les Pyrénées, le Permien n'existe que sous forme de conglomérats et de grès, surmontés parfois par des coulées de roches volcaniques basiques. Les forages prévus sur les axes anticlinaux du Sud du bassin d'Aquitaine, mais extérieurs à l'avant-fosse pyrénéenne, tels que celui de Roquefort-Créon-Lavardens, pourront nous donner des renseignements sur ce point.

Pour conclure, on peut admettre à l'heure actuelle qu'en dehors de l'Oligocène et du Crétacé inférieur qui ont pu intervenir dans la constitution de certains gisements de pétrole localisés dans le Languedoc oriental, en dehors aussi du Lias marneux dont le rôle est encore problématique, même dans le Languedoc, c'est vraisemblablement le Crétacé supérieur et moyen qui comporte les roches-mères du Sud de l'Aquitaine et le Permien inférieur celles du Languedoc. Il est cependant possible que ces dernières existent aussi sous le remplissage secondaire et tertiaire de l'avant-pays pyrénéen. Les formations lagunaires du Keuper, auxquelles on a parfois cru pouvoir attribuer un rôle dans la formation des hydrocarbures, n'ont aucun caractère de roche-mère. Enfin, l'intervention de formations pétrolifères, plus anciennes que le Permien (ou que le Stéphanien) est peu probable, aussi bien dans l'Aquitaine que dans le Languedoc méditerranéen, car les sédiments paléozoïques plus anciens de ces régions, ont été fortement affectés par les plissements hercyniens pendant le Carbonifère, parfois même ils ont subi un métamorphisme notable, et il est peu vraisemblable que d'importantes accumulations d'hydrocarbures aient pu subsister pour migrer ultérieurement dans la couverture secondaire transgressive.

(b) *Résultats stratigraphiques et tectoniques.*—Les études géologiques détaillées faites au cours de ces dernières années, jointes aux données fournies par les forages et par les observations géophysiques (gravimétriques, telluriques et sismiques) ont permis de préciser sur beaucoup de points nos connaissances relatives à stratigraphie et la tectonique des régions prospectées. Il ne saurait être question de passer en revue tous les faits nouveaux mis en évidence, mais il est possible de schématiser, d'une façon sommaire, les résultats essentiels obtenus.

Dans l'Aquitaine méridionale, bien que la limite septentrionale du sillon albo-aptien ou nord-pyrénéen soit encore indécise, il est établi que le Crétacé moyen ne débordait guère la zone plissée pyrénéenne dans sa partie orientale, alors qu'il se rencontre avec de fortes épaisseurs dans l'anticlinal de Puymaurin, au Nord des Petites-Pyrénées, dans les anticlinaux d'Audignon, de Bastenne et de Louer, au voisinage de l'Adour, entre Mont-de-Marsan et Orthez, et enfin plus au Nord encore dans l'anticlinal de Roquefort. Ainsi, bien que les très grandes épaisseurs d'Aptien et d'Albien soient localisées dans un sillon qui s'étend depuis la région d'Estagel (Pyrénées-Orientales) jusqu'au Sud de Saint-Palais (Basses-Pyrénées), une zone de subsidence comportant encore des dépôts épais avec intercalations dolomitiques, se poursuivant très loin vers le Nord dans le SW du bassin d'Aquitaine. Une ligne de hauts fonds, véritables cordillères, a dû cependant séparer en bien des points, le sillon nord-pyrénéen de ses dépendances septentrionales. La réduction du Crétacé moyen dans les Petites-Pyrénées peut s'expliquer par l'existence de ces accidents tectoniques et par la mise en place de noyaux diapirs de gypse du Trias.

Au Crétacé supérieur par contre, l'avant-fosse étroite, extérieure au domaine plissé pyrénéen, dans laquelle a été rejetée la mer lors des plissements ante-cénomaniens de la chaîne, et qui s'étendait depuis le Sud du Massif de Monthoumet à l'Est jusqu'au delà de Salies-de-Béarn à l'Ouest, a débordé beaucoup moins largement que le sillon albo-aptien vers le Nord, dans le SW du bassin d'Aquitaine. Alors que le flysch qui remplit l'avant-fosse peut atteindre 4,000 m. d'épaisseur, les dépôts contemporains qui la bordent sur la marge épicontinentale ne dépassent pas quelques dizaines de mètres en général; ce sont des formations néritiques, surtout calcaires.

L'étude des variations de faciès dans l'avant-fosse, la présence de brèches à la base du Flysch en particulier, a permis de mettre en évidence l'existence d'anciennes cordillères au Nord du front

pyrénéen. Ces cordillères ont joué au cours des diverses phases orogéniques, et ont contribué à la formation des plis des Petites-Pyrénées. Il faut remarquer toutefois que les cônes de déjection qui se sont établis sur le flanc nord des Pyrénées mésozoïques, après la phase orogénique antecénomanienne ont dû aussi contribuer largement à la variation fréquente des faciès dans le flysch de l'avant-fosse. La présence d'intercalations gréseuses dans le Crétacé supérieur peut ainsi s'expliquer sans faire intervenir des hauts-fonds hypothétiques. Nos connaissances sur la tectonique du Sud de l'Aquitaine ont été aussi largement accrues, plus particulièrement par les recherches géophysiques. Trois alignements anticlinaux sensiblement ESE-WNW, mais sinueux ont été ainsi mis en évidence sous la couverture miocène de la région SW du Bassin aquitain à l'Ouest de la Garonne: (1) l'anticlinal de Garlin, le plus méridional, au Nord de Pau, prolonge peut-être l'anticlinal de Gensac des Petites-Pyrénées; (2) l'alignement anticlinal de Puymaurin et l'Antin, au Nord des Petites-Pyrénées et de Tarbes, semble se poursuivre jusqu'à l'Adour, au Nord du précédent; (3) enfin l'anticlinal de Saint-Médard, le plus septentrional, est situé au Sud d'Auch.

Les forages déjà effectués sur les anticlinaux des Petites-Pyrénées et sur les nouvelles structures découvertes par la prospection géophysique ont montré que la plupart de ces plis ont un noyau diapir formé de gypse ou d'anhydrite du Keuper parfois à double déversement (St. Marcet).*

Plus à l'Est, au Sud de Toulouse, un haut fond a été mis en évidence près de Muret, mais bien qu'il soit situé sur la prolongation orientale de l'axe anticlinal Roquefort-Créon-Lavardens, son rattachement à cette structure paraît encore incertaine.

Enfin, dans la partie SE du Bassin aquitain, un brachy-anticlinal a été reconnu près de Tréziers, entre l'Aude et l'Ariège; c'est la prolongation vers l'Ouest de l'anticlinal Nord du Massif de Monthoumet et deux forages ont permis d'y vérifier la présence du socle antéhercynien à faible profondeur, sous une épaisseur très réduite de Crétacé supérieur.

En ce qui concerne le Languedoc, les données apportées par la prospection géophysique et les forages, coordonnées grâce aux études géologiques de surface, ont permis aussi de préciser les conditions de la sédimentation, principalement un cours du Secondaire et la structure de la région.

Au point de vue stratigraphique, l'un des faits nouveaux importants mis ainsi en évidence est l'existence de Crétacé moyen constituant, avec une couverture discontinue de Crétacé supérieur marin, près de Béziers, un haut fond déterminé par les études géophysiques, puis vérifié par des forages.

Un second fait capital, découvert par le sondage effectué dans l'anticlinal de la Gardiole, situé entre Sète et Montpellier, est la réduction du Lias inférieur et l'absence de Trias, à la base de la série secondaire, suivant l'axe du pli, par suite de l'existence d'un haut fond paléozoïque imprévisible.

Enfin l'étude minutieuse des variations latérales de faciès des divers horizons du Jurassique et du Crétacé, a donné des renseignements précieux sur la localisation des roches magasin possibles. Les dolomies du Jurassique moyen par exemple, bien développées en bordure du Massif Central, font place à des calcaires marneux vers l'Est, c'est-à-dire vers la fosse vocontienne.

Dans le Languedoc occidental, plusieurs forages sont venus confirmer l'existence et l'importance des chevauchements vers la Montagne-Noire. Deux forages effectués sur le bord NW du chaînon de Saint-Chinian, ont montré, en particulier, que le Lias inférieur et le Keuper chevauchent le Danien du Minervois sur au moins 400 m. et probablement beaucoup plus. Un autre sondage situé près de Creissan a montré l'existence d'imbrications poussées vers le NW. Enfin, récemment un forage placé dans un anticlinal affecté de failles simples en apparence, près de Puisserguier, au SW du précédent, a rencontré sous l'Infra-Lias et le Keuper un conglomérat danien indiscutable à galets de calcaire aptien fossilifères.

Dans la région du seuil jurassique, au Sud des Causses, l'exploration par forage des anticlinaux

---

* Il est intéressant de noter à ce propos que les noyaux diapirs des anticlinaux des Petites Pyrénées, doivent présenter des coupes très variables le long d'un même pli, comme c'est souvent le cas dans d'autres régions (Tintea).

a conduit à des observations importantes du point de vue tectonique et structure. Un sondage effectué par l'état en 1938, dans le flanc méridional du brachy-anticlinal du Pic Saint-Loup, a montré que le déversement apparent du flanc nord du pli, correspondait en réalité à une véritable disposition en pli-faille avec une surface de chevauchement vers le Nord, inclinée à 30° vers le Sud. D'autre part, le forage destiné à l'exploration de l'anticlinal de la Gardiole, a révélé, ainsi que nous l'avons vu précédemment, l'existence d'un haut-fond paléozoïque, au-dessus duquel la série de base du Secondaire est réduite et le Permien est absent. La présence de ce socle hercynien surélevé ne saurait d'ailleurs être considéré comme la preuve de l'existence d'un massif ancien, de même caractère, sous toute la région du seuil ou éperon jurassique. Il est plus vraisemblable d'admettre que le socle hercynien de la Gardiole s'allonge suivant la direction moyenne des plis, c'est-à-dire vers l'ENE. Il pourrait en résulter des variations de faciès, avec apparition de roches détritiques ou néritiques poreuses, favorables à l'accumulation du pétrole dans le Sud du Languedoc occidental, comme il s'en présente au voisinage des Cévennes, vers le Nord. Bien des observations de surface permettent au contraire de penser que l'ennoyage des Causses, et son confluent avec le Bassin du Languedoc, entre la Montagne-Noire et les Cévennes, ont dû déjà jouer comme fosse de subsidence au cours du Permien.

Dans le Languedoc oriental, la prospection géophysique a permis de déterminer les grandes lignes de la structure des régions recouvertes par le Miocène, le Pliocène et le Quaternaire. Une faille très étendue, suivant à peu près la direction de la voie ferrée entre Lunel et Nîmes, abaisse brutalement le substratum secondaire de plus de 1,000 m. dans la lèvre sud. Il en résulte, sous la vallée de la Vistre, un fossé profond à direction WSW—ENE, qui a été remblayé vraisemblablement par l'Oligocène et le Néogène. Vers le Sud, le substratum secondaire se relève progressivement, mais il est affecté de bossellements dont trois bien caractérisés dans la Camargue paraissent pouvoir être interprétés comme des brachy-anticlinaux.

CONCLUSIONS

Les recherches entreprises dans le midi de la France depuis quelques années, entre l'Océan et le Rhône, n'ont conduit jusqu'ici qu'à la découverte d'un très important gisement d'hydrocarbures gazeux, à Saint-Marcet, dans les Petites-Pyrénées, mais la découverte à brève échéance d'autres gisements exploitables de pétrole ou de gaz, paraît vraisemblable, étant donné les résultats déjà acquis à Audignon, Plagnes et la Vaunage notamment. Au surplus, il est possible que la présence de pétrole dans le gisement de Saint-Marcet, ne soit pas un simple accident local, comme on paraît l'admettre actuellement.

Les données géologiques résultant des recherches effectuées pour découvrir du pétrole, tant par les géologues que par les géophysiciens et les sondeurs, ont, à côté d'un intérêt pratique pour la localisation de la prospection, un intérêt théorique non moins certain pour enricher nos connaissances sur la stratigraphie et la tectonique des régions explorées.

L'identification des roches-mères est encore du domaine de l'hypothèse, mais quelques forages nouveaux dans l'Aquitaine, au Nord des sillons de subsidence, et dans le Languedoc, principalement sur le seuil jurassique, pourront apporter beaucoup de lumière sur le rôle des formations paléozoïques supérieures, principalement du Permien, dans la formation du pétrole.

Il pourrait paraître prématuré de rechercher a quels types de gisements il est possible de rapporter ceux qui sont encore en cours de prospection dans le midi de la France. Cependant le gîte de gaz de Saint-Marcet appartient indiscutablement au type d'avant-fosse de chaîne plissée, ce qui n'entraîne pas nécessairement la formation exclusive des hydrocarbures à partir des sédiments ayant remblayé cette avant-fosse. En effet, dans bien des chaînes plissées, l'avant-fosse se constitue non pas sur l'avant-pays du géosynclinal ou du sillon de subsidence d'où la chaîne est issue, mais aux dépens de ces zones de subsidence elles-mêmes. Dans ce cas, les dépôts de bordure de l'ancien bassin de subsidence, qui ont été recouvertes par les sédiments accumulés dans l'avant-fosse, ont pu participer au même titre que ces derniers à la constitution de gisements pétrolifères, et c'est le cas notamment dans l'avant-fosse

des Appalacnes. Dans la chaîne plissée, soit par suite de leurs faciès plus bathyaux, soit encore par suite des dislocations intenses qu'ils ont subi, parfois aussi d'un métamorphisme plus ou moins accusé qui les a affectées, ces formations sédimentaires antérieures à la formation de la chaîne ne sont pas pétrolifères.

DISCUSSION

J. CUVILLIER said that he would like to add that recently at Bastennes-Gaujacq (Landes) in Aquitaine, the deepest boring in France, and probably in Europe, had found oil and gas at a depth of 4,160 m. A continuous succession from Middle Eocene to Aptian had been penetrated. The source of the oil and gas was believed to be in the Jurassic.

W. L. F. NUTTALL remarked that M. Barrabé had explained that the Aquitaine Basin consisted of two parts separated by a basement uplift, and that it would be of interest to have a description of the structural and stratigraphical conditions in the northern part of the Basin, together with a comparison with those of the southern part which had been described in some detail.

L. G. WEEKS also asked for additional information on the structure and stratigraphy of the north Aquitaine Basin.

G. M. LEES sought for a further description from M. Barrabé of the complex structures lying to the north of the Pyrenees front.

L. BARRABÉ replied:

1. Que les variations latérales de facies et de séries stratigraphique entre l'Aquitaine et le Languedoc sont exposées dans la texte de la note.

2. Que la tectonique de détail des structures prospectées n'a pas pu être exposée faute de temps. La coupe probable de l'anticlinal de St. Marcet avec son noyau diapir poussé au Nord et rejetté vers le sud par une faille inverse, a déjà été publiée.

3. Que le Nord du Bassin d'Aquitaine a été laissé de côté du fait qu'il pose des problèmes bien différente de ceux examinés au sujet du bassin sud-aquitain. Les séries stratigraphiques sont moins épaisses et les facies moins profonds.

SIGNIFICANCE OF WORLD'S DEEPEST WELL BORE

By ROBERT R. WHEELER and LOUIS S. WALLACE

U.S.A.

ABSTRACT

The deepest well in the world was abandoned by the Superior Oil Company in August, 1947, at a total depth of 17,823 feet after having penetrated about 5,000 feet of Permian and more than 12,000 feet of Pennsylvanian rocks near the axis of the Anadarko Basin bordering the Wichita Mountains of Oklahoma.

The significance of this deep test is threefold; geological, to the extent that it adds valuable stratigraphic data and aids in dating the orogenic movements that created the Anadarko Basin; economic, in evaluating the pre-requisites of porosity, proximity of source beds and nature of the structure as a trap for oil; and engineering, because this extremely deep hole indicated much of value regarding the strength and performance of modern drilling equipment.

Of the greatest geological interest was the penetration of some 3,500 feet of Deese (Des Moines) which lies uncon-formably upon truncated early Pennsylvanian Atoka glauconitic limestones and sandstones. Abundant subsurface stratigraphic evidence around the up-faulted margins of this Anadarko Basin where the Deese laps-out completely had already indicated that the Arbuckle-Wichita orogenic movements were initiated during early Pennsylvanian time, beginning with truncation of the Morrow and older pre-Pennsylvanian rocks, and culminating in post-Atoka pre-Des Moines time, in contrast to the post-Mississippian pre-Pennsylvanian date that had long been assumed by Mid-Continent geologists in conformity with a generally accepted late Mississippian world-wide interval of diastrophism.

Superior's test, located on the crest of a reflection seismic dome showing several hundred feet of closure, cored steep dips in the Lower Pennsylvanian, indicative of a lateral shift of the structural axis with depth.

Spectacular records for the deepest fishing job, the longest string of casing ever set, and the deepest drill-stem testing and coring, were accomplished with equipment capable of 500-ton tensional stress and at subsurface temperatures in excess of 260°F., at an unofficially estimated cost of three-quarters of a million dollars.

INTRODUCTION

THE deepest well bore in the world was drilled to a total depth of 17,823 feet in western Oklahoma as a rank wildcat venture located in a dissected portion of the Great Plains of the Mid-Continent of North America, a region that was formerly valuable grazing land, now deeply cut by gullies and inhabited by the blanket-clad and impoverished descendants of Apache and Comanche Indians. It tested a large structural feature which had been mapped by reflection seismograph surveys in the deep trough of the Anadarko Basin bordering the Wichita Mountains of western Oklahoma (Fig. 1). This exceedingly expensive undertaking is significant from several viewpoints, not only for its bearing upon the geological history of a province that to date has been only superficially explored for oil, but also from the engineering and economic aspects involving the strength and performance of modern drilling equipment and the cost of deep prospecting.

PERFORMANCE OF DRILLING EQUIPMENT

This deep test was drilled by the Superior Oil Company of California with a large steam-powered rig consisting of five boilers of 1,750 pounds per square inch total pressure capacity and heavy duty draw-works and engines mounted in a 176-foot tall derrick. This equipment succeeded in lifting the longest and heaviest string of steel casing ever cemented in a well bore (weighing over 500,000 pounds) and, even at a depth of three miles, could pull the drill-pipe out of the hole faster than an average rig at one-third this depth.

While drilling below 17,000 feet, the walls of the hole caved in around the drill-pipe, but after two months of spectacular effort, the drill-pipe was entirely removed from the hole and normal drilling
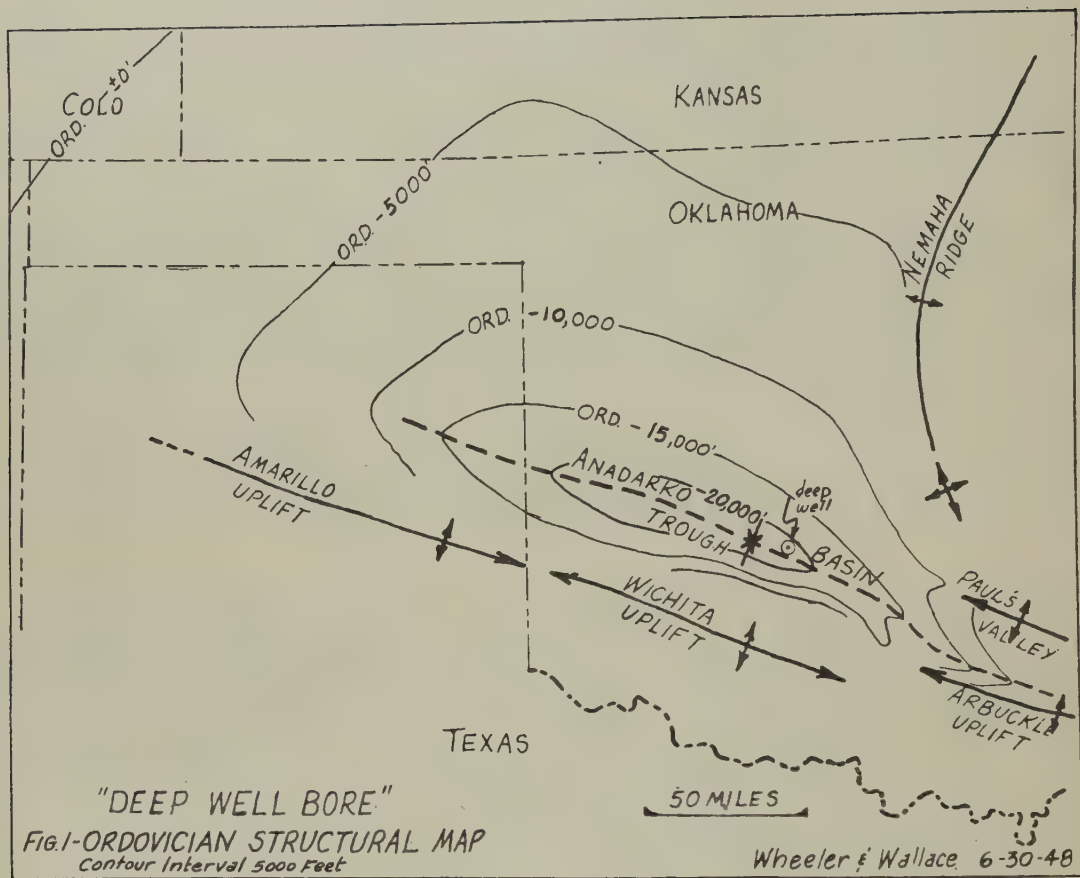
FIG. 1.

resumed. But the walls continued to cave into the hole, so that at 17,823 feet deeper drilling was halted in order not to jeopardize shows of oil and gas up the hole. All prospective showings were tested during the next two months through perforations in the casing. These production tests failed to show commercial possibilities and the well was plugged and abandoned on 13th August, 1947.

The expense of drilling is unofficially estimated at three-quarters of a million dollars, but this figure might be raised to a million dollars to include depreciation of equipment and five strings of drill-pipe, the casing left in the hole and the production tests involving repeated perforating, drill-stem testing and recementing of abandoned sections.

Of especial interest were surveys showing (1) temperatures of 265°F. at about 17,000 feet, (2) electrical logging records at frequent intervals by which a composite log of the entire hole was made available to the industry, and (3) evidence of abnormally high pressures. These excessive pressures of more than 12,000 pounds per square inch were nearly twice the normal hydrostatic pressure at 17,000 feet and are attributed to thin zones of high gas pressure sand such that gas invaded the mud and reversed the flow of self-induced electrical current of the logging instrument. Thus, to cope with the gas invasion, the drilling mud had to be maintained at an extremely high density (110 pounds per cubic foot) and viscosity at a cost of $36,000, which expense alone would have drilled an average 6,000-foot well in this region.

STRUCTURAL PATTERN

The Superior deep test was located on a more or less symmetrical dome of several hundred feet of closure trending north-west—south-east, parallel to the alignment of the majority of faults and flexures associated with the Arbuckle-Wichita-Amarillo Uplift of southern Oklahoma. Here the trend of the major structural features is west—north-west with a pattern of thrusting, overturning and normal faulting of great displacement along the north flanks of the mountain uplifts. The secondary grain of structural features is more of an *en échelon* pattern of north-west trending faulted folds in which the amount of closure is, to some extent, proportionate to the displacement of the accompanying faults so that as the faults die out basinward from the mountain source of stress, the amount of closure also diminishes. Thus, the mountain flanks and basin trough are characterized by large persistent domes of moderate displacement and relief, whereas the northern basin flanks most distant from the source of stress contain folds of least magnitude and only occasional faults. Due to the interrupting effect of both early and late Pennsylvanian structural movements, the features of this region show an increase in relief with depth. Where domes and basins of several hundred feet of structural relief have been truncated due to early movements and overlapped by relatively unwarped non-marine red beds, the deeper structures are not ordinarily reflected at the surface.

STRATIGRAPHIC SEQUENCE

Upper Permian sands and red shales of non-marine origin are exposed in the vicinity of the deep well. These and mid-Permian evaporitic deposits extend to a depth of 3,900 feet where Lower Permian marine limestones were encountered. Both the early Permian and late Pennsylvanian " Cisco " beds grade mountainward into an increasingly arkosic facies called " Pontotoc " so that they are only tentatively separated at a depth of 4,950 feet.

Reference to the correlation chart (Fig. 2) will indicate that the loosely used late Pennsylvanian term " Cisco " refers to a predominantly marine sequence of Virgil age. Commonly the Cisco is lost by truncation around the flanks of the basin where the Hoxbar (of Missouri age) constitutes the upper Pennsylvanian. But in the deep well, Cisco and Hoxbar rocks were well represented to a depth of about 10,600 feet. The lower Hoxbar sands that are porous and prolific producing zones to the south on the basin flanks were fine-grained and tightly cemented in this well, but the lower 500 feet of sandy oolitic Hoxbar limestone definitely established correlation with better known areas.

B   17

The underlying Deese sequence of mid-Pennsylvanian (Des Moines) age consisted of 2,500 feet of grey shale with poorly developed siliceous sand members and a moderately porous 30-foot sand at the base (13,000 feet). Unconformably beneath the Deese are upper Dornick Hills (Atoka) shales with dense brown limestone beds becoming more abundant toward the base at 15,525 feet. The lower Dornick Hills, composed of highly glauconitic siliceous limestones above and thick glauconitic sands

UPPER PALEOZOIC CORRELATION CHART

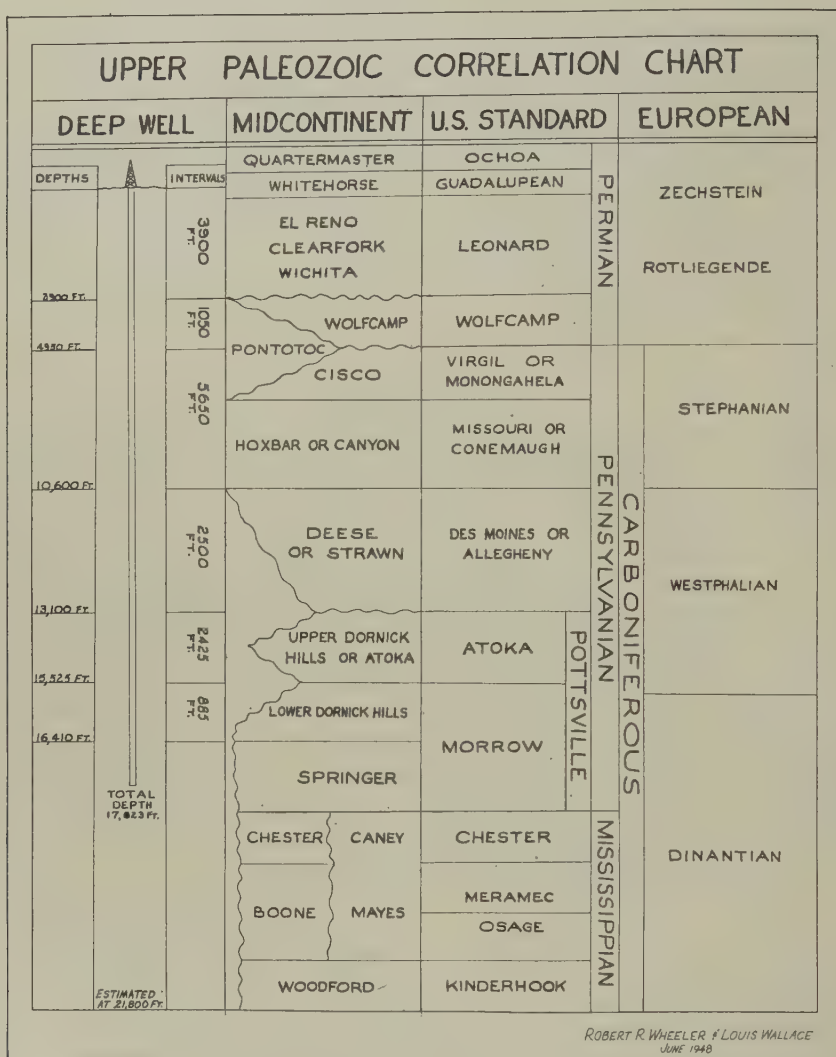| DEEP WELL		MIDCONTINENT	U.S. STANDARD		EUROPEAN
DEPTHS / INTERVALS		QUARTERMASTER	OCHOA	PERMIAN	
		WHITEHORSE	GUADALUPEAN		ZECHSTEIN
	3900 FT.	EL RENO CLEARFORK WICHITA	LEONARD		ROTLIEGENDE
2900 FT.					
	1050 FT.	WOLFCAMP	WOLFCAMP		
4950 FT.		PONTOTOC			
	5650 FT.	CISCO	VIRGIL OR MONONGAHELA	PENNSYLVANIAN / CARBONIFEROUS	STEPHANIAN
		HOXBAR OR CANYON	MISSOURI OR CONEMAUGH		
10,600 FT.					
	2500 FT.	DEESE OR STRAWN	DES MOINES OR ALLEGHENY		WESTPHALIAN
13,100 FT.					
	2425 FT.	UPPER DORNICK HILLS OR ATOKA	ATOKA	POTTSVILLE	
15,525 FT.					
	885 FT.	LOWER DORNICK HILLS	MORROW		
16,410 FT.		SPRINGER			
TOTAL DEPTH 17,823 FT.		CHESTER / CANEY	CHESTER	MISSISSIPPIAN	DINANTIAN
		BOONE / MAYES	MERAMEC		
			OSAGE		
ESTIMATED AT 21,800 FT.		WOODFORD	KINDERHOOK		

ROBERT R. WHEELER & LOUIS WALLACE
JUNE 1948

FIG. 2.

below, constitutes the upper group of the early Pennsylvanian (Morrow) series. This sequence is preserved only in the least truncated portions of the basin. More commonly only the underlying Springer group of lower Morrow age is present beneath the overlapping beds of later age. Here, the Springer black shale sequence at 16,410 feet contained interbedded 100- to 200-foot sands correlative with producing sands to the east, but the hole was abandoned with an estimated 1,000 feet of Springer unpenetrated at 17,823 feet.

Since the relative thicknesses of these various Pennsylvanian series compared with the much thinner sequences marking the borders of the Basin have the greatest significance in evaluating the magnitude of the Pennsylvanian orogenic movements, the above data are summarized as to thicknesses:

Des Moines	—	2,500 feet.
Atoka	—	2,000 feet.
Morrow	—	2,300 feet.

Correlations with other deep basin wells that penetrated the lower Springer and pre-Pennsylvanian rocks of the region, indicate that the Superior test stopped 1,000 feet above the Mississippian, and that it is reasonable to anticipate that the Superior well would have encountered the Siluro-Devonian (Hunton) group at 21,800-foot depth, the Ordovician at 22,400-foot depth, and the pre-Cambrian at about 30,000 feet.

The Superior deep test supplies valuable data in deciphering the age and magnitude of the major orogenic events. For example, in finding preserved higher members of the Morrow series than are ordinarily present in regionally higher wells, we are better able to estimate the total thickness of Pennsylvanian rocks in the Anadarko Basin.

Also of great interest was the presence of lower Pennsylvanian Atoka rocks which were not definitely to be anticipated from the previously known distribution of Atoka rocks along the eastern margin of the Anadarko Basin.* The evidence from the Superior well, plus revised studies† in the northern embayment of the Anadarko Basin and Kansas, shows that there must be a belt of Atoka rocks preserved in areas of negative anomalies extending north-westward across the basin, but evidently not coinciding with the axis of the Anadarko Basin. One must infer that late Atoka structural movements left depressions in which Atoka rocks are preserved, whereas on the nearby uplifts these rocks have been locally truncated and overlapped by abnormally thin Des Moines beds.

A third point of significance to be gained from the Superior test was the thickness of the Des Moines section totalling approximately 2,500 feet, which is appreciably less than the 3,500-foot thickest sections yet penetrated in the basin, and may possibly be attributable to the magnitude of the Superior structure in view of the fact that the Des Moines series thins rapidly upon the basin flanks and is totally lacking about 60 miles to the east on the structurally high Pauls Valley Uplift where the succeeding Hoxbar rests unconformably upon the truncated older rocks.

Probably the most significant aspects of this deep test and its corroboration of the historical geological events that created the Arbuckle-Wichita Mountain system and the adjacent Anadarko Basin are the implications in regard to the relative age of orogenic movements in the Mid-Continent compared to those assumed to exist elsewhere in the world. Ever since Chamberlin, some 40 years ago, advanced the concept of world-wide and simultaneous mountain building, such writers as Bucher, Stille, Schuchert and others have attempted to subdivide the geological column for the world on the basis of a concept of periodic, widespread diastrophism. One of the more prominent of these was supposed to separate the Pennsylvanian from the Mississippian system, not only in North America, but particularly in Europe where Stille set the age of the great Sudetic epoch of folding at the Mississippian-Pennsylvanian boundary, asserting that this corresponded with the Wichita and Ouachita epoch of folding in the Mid-Continent of North America and with orogenic movement in other parts of the world. But the evidence in the thicker sequences of the Mid-Continent indicates that any late Mississippian movement was of negligible consequence compared to the two early intervals of mountain building that occurred just preceding and following Atoka time and initiated the southern Oklahoma structural system.

Whereas much precedent has been established, especially by students of European stratigraphy, for the grouping of later Paleozoic rocks into one system of Carboniferous age, it has become desirable,

---

* WHEELER. Anadarko Basin, Geology and Oil Possibilities. *World Oil*, vol. 127, nos. 4, 5, 7, 9 (1947–48).

† MAHER and COLLINS. Hugoton Embayment of Anadarko Basin. *Bull. Amer. Assoc. Petrol. Geol.*, vol. 32, May, 1948, p. 813.

in regions such as the Appalachian geosyncline and the Mid-Continent province of North America where many thousands of feet of Carboniferous rocks were deposited, to subdivide these, not only into mappable units for convenient correlation, but where the evidence is so plain as to the interrupting influence of major mountain-building movements, the American practice of setting off thick genetic units of systemic rank seems justified. In other words, we deal here with some 3,000 feet of Mississippian rocks, 13,000 to 14,000 feet of Pennsylvanian rocks, and about 5,000 feet of Permian rocks which are merely a thin marginal facies of the much thicker Permian Basin sequence of West Texas.
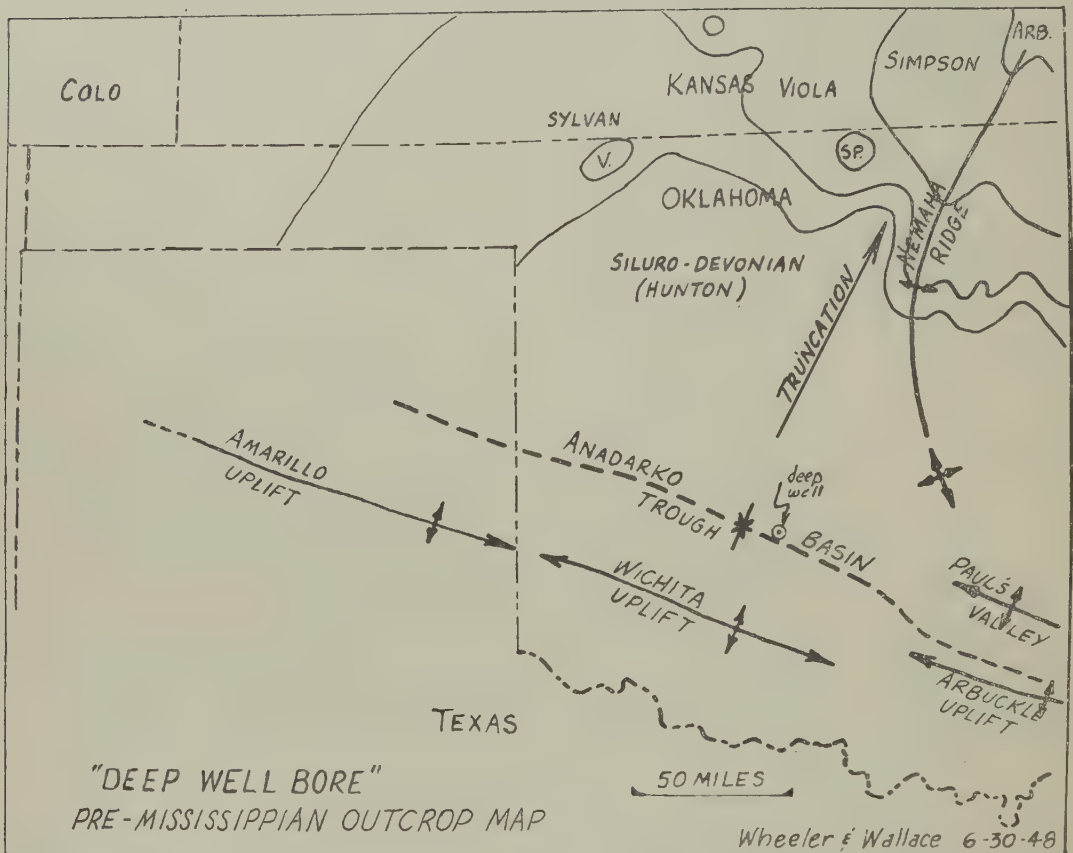

FIG. 3.

GEOLOGIC HISTORY OF THE REGION

During early Paleozoic time, before the Arbuckle-Wichita-Amarillo Uplift had come into existence, much of the Mid-Continent was occupied by a widespread sea centering in southern Oklahoma. Deposition continued from Upper Cambrian into early Pennsylvanian time in the deeper parts of this basin without any important interruptions, although structural movements occurred across the northern flank of the basin in central Kansas and north-eastern Oklahoma so that in these latter areas there are numerous unconformities recognized with truncation and onlap responsible for

the much abbreviated over-all stratigraphic sequence. Even the early Mississippian tilting that necessitated the truncation of the underlying Siluro-Devonian and Ordovician rocks to the north-east (Fig. 3) did not seriously interrupt the mid-Paleozoic deposition of the deeper basin areas in southern Oklahoma. Neither did late Mississippian movements, that established a measurable pre-Pennsylvanian unconformity across the northern margins of the basin, seem to have affected more than very locally the transitional black shale deposition of late Mississippian and early Pennsylvanian times in this original geosyncline. It is true that the pre-Pennsylvanian rocks show local small-scale truncation in southern Oklahoma, but this is not comparable to the successive truncation and Mississippian overlap of the Hunton limestone, Sylvan shale, Viola limestone, Simpson group and Arbuckle (of Devonian
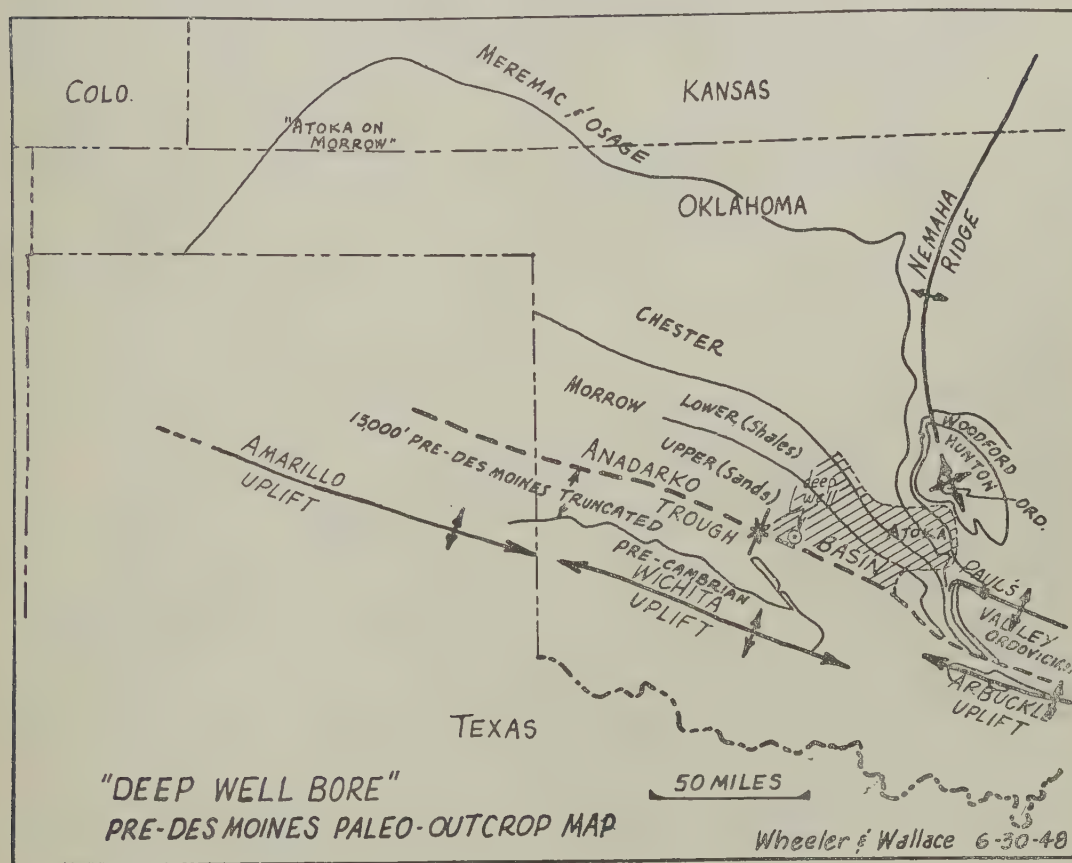

FIG. 4.

to Cambrian age) that occur peripheral to the Central Kansas and Ozark Uplifts to the north and east.

However, during early Pennsylvanian time the general Arbuckle-Wichita-Amarillo arch came into existence through two main epochs of uplift accompanied by adjustment-type faulting and folding. The first of these occurred in late Morrow time, the second in late Atoka pre-Des Moines time. As a consequence of these two lower Pennsylvanian orogenic movements (see Fig. 4) about 15,000 feet of pre-Des Moines sediments were bevelled off along the mountain axes to expose granite, and two new troughs were established, the Anadarko Basin bordering the mountains on the north and the Ardmore Basin to the south. The remainder of Pennsylvanian time was characterized by onlap across the

truncated and downwarped older terrain with frequent interruptions of deposition on a more local scale that produced great lenticularity of bedding and a greater abundance of clastic deposition compared to the older sequence. The magnitude of Des Moines onlap amounting to 3,500 feet to the east is shown in Fig. 5.

Again in late Pennsylvanian time, the entire structural system was rejuvenated with large scale faulting, but whereas the pre-Des Moines structural relief was reduced to base-level prior to overlap, the late Pennsylvanian movements created fault-block topography that was rapidly buried by a thick mantle of predominantly non-marine arkosic conglomerates generally referred to as the Pontotoc " terrain." The succeeding Permian deposition commenced with a sequence of limestones and dolo-
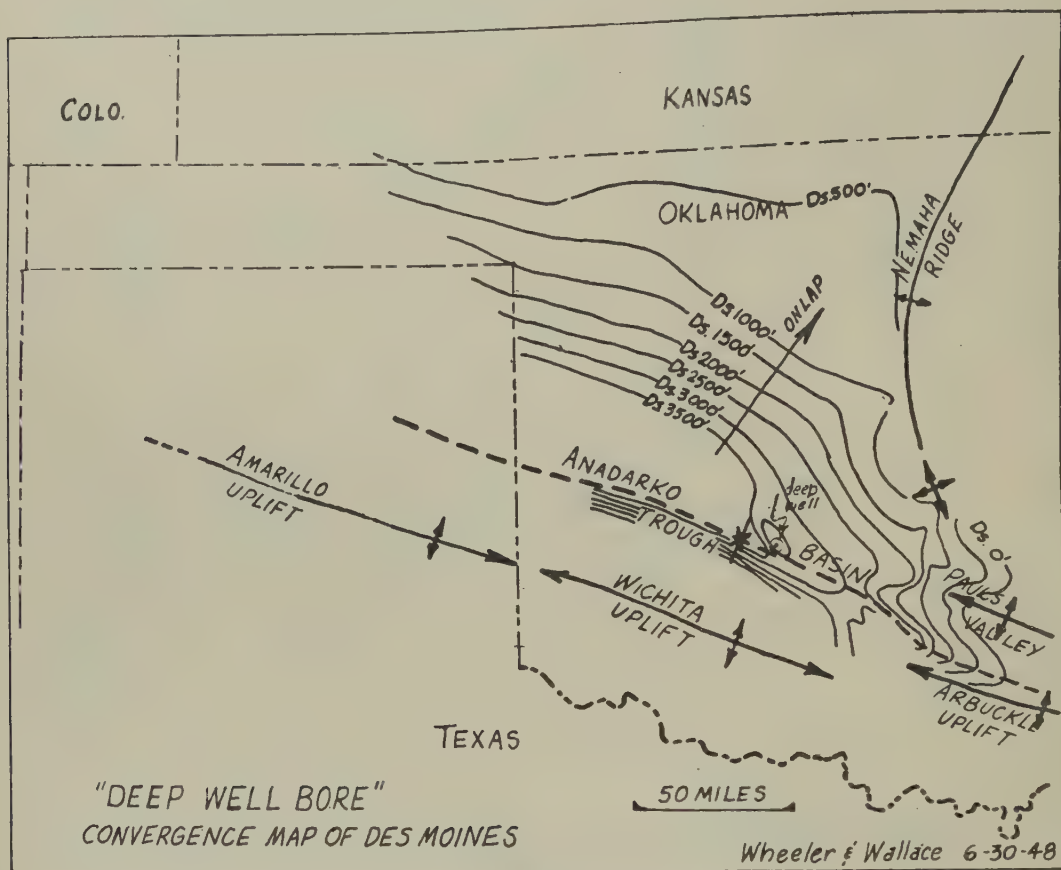

FIG. 5.

mites interfingering with and compensating for the topographic relief of the Pontotoc, but the character of deposition changed abruptly in early mid-Permian time to predominantly non-marine evaporitic deposition (gypsum, salt and red beds) due to restricted circulation of the Permian seas to the south. This Permian movement was of considerable over-all relief amounting to about 3,000 feet from the south-west corner of Kansas to the basin trough. The cumulative effect of these late Paleozoic movements was to depress the basement rocks approximately 30,000 feet below the present position of pre-Cambrian granite exposures a few miles south in fault-blocks of the Wichita Mountains in a structural system of far greater magnitude and complexity than had ever been inferred from the surface mapping of the region.

DISCUSSION

V. C. ILLING observed that deep wells must be drilled, and enquired what was the depth of the deepest drillstem tests, and whether it was considered that 30,000-foot wells would eventually be drilled.

M. R. AGUILAR asked whether the drilling of these deep wells was economically worth while.

R. D. FORD enquired if any permeable beds were found in the deeper formations.

G. W. HALSE commented on the author's remarks about difficulties due to caving, and the use of 110lb./cubic foot mud. He asked whether there were any reasons for not using heavier mud to reduce caving risks, mentioning that in Trinidad it was normal practice to use mud of 125–135lb./cubic foot.

R. R. WHEELER replied that in the case of the Superior deep test there was reason to expect from the records of nearby deep wells that thick porous sands would be encountered in the Lower Pennsylvanian between 13,000 feet and 15,000 feet. Had such sands been penetrated and found oil-bearing the venture might well have been a commercial success. On failing to find such porous sands the well was deepened out of curiosity regarding specific deeper objectives, and because no certainty existed concerning the prospects of other unpredictable reservoir rocks.

With regard to deep drilling in general it should be noted that hardness of the formations was as important as depth, especially where a generally siliceous facies (Arbuckle Mountain flanks) or steep dips were encountered, and the maintenance of a straight hole required slow drilling. In his opinion it was unlikely that such deep drilling would ever be economic unless very thick sands were met.

In the Superior well the only permeable sands of any importance were encountered at about 8,200 to 8,300 feet. These were not tested in drilling the section, but were tested through perforations in the casing just before the well was abandoned, and after drilling mud had seriously penetrated the formation. Most of the zones of porosity were drillstem tested.

Weighting of the drilling mud to 110lb./cubic foot seemed more than adequate to deal with any pressures expected, wheareas excessive weighting would have slowed down the rate of drilling.

AN AID TO THE FORECASTING OF UNDERGROUND STRUCTURES

By H. R. TAINSH

Burma

ABSTRACT

This short note essentially concerns the search for oil pools associated with folded sedimentary rocks. Some structures have been tested to depths of 12,000 feet or more, but elsewhere many folds are yet untested; in most oil provinces, deeper prospects must be re-examined as drilling below 15,000 feet becomes a routine operation.

There has been much work on the geometry of folding, but the relation between theoretical solutions and actual sections, particularly when extrapolated to great depths, is largely unknown.

There are admittedly many difficulties in the prediction of underground structures, but on the basis of the tentative sections drawn by geologists, oil companies each year locate and drill many expensive wells. The value of the section depends very much upon the experience of the geologist; as so little is published on the subject, the student and the geologist of limited experience have no easy means of guidance.

It is suggested that great assistance could be given to oil exploration and to the general study of structural geology if a comprehensive collection could be made of measured sections at depth, showing competent and incompetent folding, and faulting.

The compilation would be a large task, but would be of value to all who are interested in the structure of the earth's surface.

DISCUSSION

P. Evans, speaking from the Chair, emphasized that the background to Mr. Tainsh's proposal was not the structure with a maximum dip of a few degrees, but the more sharply folded asymmetrical anticline in which it was impossible to predict with the required accuracy the shape of a bed at depths which could be reached in a test well. Any studies which would materially reduce the chances of locating test wells " off structure " would be a great help in lowering the cost of prospecting.

V. C. Illing noted that sections are frequently drawn with different vertical and horizontal scales. This practice led to distortion of the picture and was to be strongly deprecated. The various problems involved solid geometry, and in constructing sections not only surface data, but also deep information must be used.

F. E. Welling stressed the importance of what Professor Illing had said about solid geometry and underground structure. For the construction of cross-sections from surface dips he called attention to H. G. Busk's book on *Earth Flexures*, which was not as well known, particularly to Americans, as it deserved to be.

In reply H. R. Tainsh said that the geometrical methods of section construction in Busk's *Earth Flexures* were of value only where the beds were folded in concentric arcs, but did not apply where there was incompetence. (The work of Coates was more comprehensive in this respect.) One great value of a world-wide collection of geological sections would be the opportunity provided for formulating a general scheme for interpreting structure at depth.

In closing the discussion P. Evans expressed the hope that in spite of the obvious difficulties involved, there would be strong support for Mr. Tainsh's proposals.

SOME ASPECTS OF PETROLEUM MIGRATION

By W. B. WILSON
U.S.A.

ABSTRACT

Evidence is now cumulative to the degree of being overwhelming that petroleum has everywhere migrated up dip in water-wet reservoir beds, until arrested by a definite trapping situation or by arrival at outcrops with subsequent dissipation in the atmosphere. This is true without regard to distances involved. A flattening in dip, other factors being unchanged, nowhere accounts for commercial accumulations of petroleum. Evidence is now satisfactory that under favourable but not unusual circumstances, oil will move up dips of no more than one foot per mile, and moreover that long periods of geological time are not necessary for such migration. Past laboratory experiments on oil migration have not sufficiently duplicated natural conditions, and more comprehensive ones are in prospect now that materials are more readily available.

DISCUSSION

The Chairman, P. EVANS, said that it was impossible in the short time remaining to discuss fully the fundamental problems mentioned by Mr. Wilson, but he hoped that several members could make brief contributions to the discussion.

R. R. WHEELER enquired whether the author considered that in a region such as the great central portion of the Anadarko Basin of western Oklahoma, where early folds of negligible closure existed and where there was no likelihood of the introduction of later oil through the juxtaposition of new source beds, either by overlap or by faulting, such closures as now exist in the Simpson sands were likely to be barren even though these sands produced oil round the margins of the basin in southern Kansas and eastern Oklahoma where the Simpson oil migrated prior to the early Pennsylvanian folding.

L. C. STEVENS referred to Mr. Wilson's mention of the existence of " inclined water tables " and his possible explanations of this phenomenon. A possible factor which was not mentioned was, however, the influence of " permeability." Variations in the permeability of the reservoir rock from one part of a field to another, either horizontally or vertically, may cause the water table to be higher in an area of relatively low permeability due to the increase in the " capillary forces."

The speaker had noticed that fields having perfectly level water tables were usually of uniformly high permeability, such as the case of East Texas mentioned by the author, while those with a variable or inclined water table were usually of a lower order of permeability, and subject to considerable variations from one part of the reservoir to another; for instance when a water table cut obliquely across the dip of the formations it might pass from a sand development of relatively low permeability into beds of higher permeability or vice versa without any discontinuity of the permeable beds.

L. OWEN remarked that Mr. Wilson had dealt only with migration along or through strata of relatively high permeability, and along relatively wide channels. In such cases it was rare that the chemical and physical properties of the oil were substantially modified; it was to be expected, also, that the oil-water interface would remain approximately parallel to the iso-gravity planes, which were normally horizontal. On the other hand, where migration had taken place through media of relatively low permeability, and along channels of capillary or near-capillary dimensions, the chemical and physical properties might be considerably modified, and, moreover, the several oil-water interfaces in the normally lenticular reservoirs, in which the oil collects under such conditions, were rarely in the same horizontal plane—even approximately.

This question of chemical and physical change during migration had a practical application in as far that the course of the migration could often be traced by this means and its extent sometimes estimated.

W. B. WILSON, replying to the discussion, expressed his belief in the early accumulation of oil. Stratigraphic traps might be present at an early date while structural traps appeared later, but it was possible for some folding to take place before the phase of deposition was ended.

The Simpson oil prospects seemed to be doubtful because of the age of the folding. There was no noticeable thinning of the beds over the structures, but it was not safe to say that there was no folding in this area until Pennsylvanian times, when oil occurred in Ordovician rocks. The Simpson might still be porous unless there had been a late introduction of cementing matter.

.

SOME STRUCTURAL AND STRATIGRAPHICAL ASPECTS OF THE OILFIELDS OF THE MIDDLE EAST*†

By G. M. LEES
Great Britain

ABSTRACT

The great oilfields of the Middle East lie in a broad zone between the Zagros Mountains of Persia and Iraq and the Arabian massif. Sedimentation during the Palaeozoic was thin and incomplete, but throughout the Mesozoic and early Tertiary there was continuous deposition of dominantly calcareous strata, though with occasional intercalations of evaporites.

The main folding movement was in the late Pliocene. In front of the highly compressed central zone of the Zagros a belt of giant anticlines was formed, characterized by unusual structural simplicity and regularity. The Kirkuk oilfield is a striking example. It occupies a crest maximum, with a length of 60 miles, at the north-western end of a steep anticline which can be traced to the south-east as an individual unit for 250 miles. Probably the Cambrian Salt Series forms a lubricant which allows such freedom of movement.

The intensity of folding diminishes with the approach to the Arabian foreland. The Kuwait and Arabian oilfields are on broad and flat anticlines, though of considerable individual size.

The reservoir rock of the Iraq and Persian fields is a limestone of mid-Tertiary age with cover rocks of a salt-anhydrite-marl series of Miocene age. The Arabian oil is found at different horizons from Middle Cretaceous to Jurassic. Kuwait produces from sandstones, the other fields from limestones.

AMONG the oilfields of the world, those of the Middle East stand in a class apart. Individual fields and the yields of individual oil wells are many times the size of the average elsewhere in the world, and the proved reserves are thought to exceed those of the United States of America.

The exceptional richness of this great oilfield province is the consequence of an unusually favourable conjunction of all the factors which control oil accumulations—original richness of source rocks, good reservoir rocks, large anticlines with extensive drainage areas and excellent cover rocks preventing the escape of oil to the surface. The combination of these factors has given rise to oil accumulations on a giant scale. The great East Texas oilfield has, until recently, been regarded as the world's largest with an estimated ultimate production of about 700 million tons, but among the oilfields of the U.S.A. this is a solitary giant, the next biggest being Sunset-Midway credited with 115 million tons. The Middle East fields may average several hundred million tons, with some fields rivalling or exceeding East Texas in size, Kirkuk and Kuwait, for example.

The oilfields of the Middle East so far developed lie in Persia, Iraq, and along the southern littoral of the Persian Gulf in the states of Kuwait, Saudi Arabia, Bahrein Island, and Qatar; and exploration surveys or exploration drilling are in active progress in the Trucial States of Arabia, in Oman and southern Arabia and in Syria, Lebanon, Palestine, and Transjordan. The proved fields fall into two groups, those in the foot-hill phase of the Zagros Mountains and those in the gently folded Arabian foreland (Fig. 1).

The Zagros Mountains are the sector in Iraq and South-west Persia of the Dinarid branch of the Alpine mountain system, mountains arising out of the great Tethys geosyncline. In the more north-easterly zones orogenic movements commenced in early Cretaceous and a phase in Upper Cretaceous attained an intensity which gave rise to great thrust sheets. The zone in which the oilfields were

---

situated, however, remained almost undisturbed from early Cambrian time until the great phase of compression in the Pliocene caused intense folding and thrusting—great earth waves directed towards the rigid mass of Arabia.

During the Palaeozoic, sedimentation was not continuous but no evidence is known of any angular discordances indicating important movements (for more detailed description of stratigraphy see Lees and Richardson, 1940). The Cambrian is noteworthy for its salt deposits which have subsequently intruded their cover to form the great salt plugs of the Persian Gulf area. Ordovician to Carboniferous periods are poorly represented as thin shales and sandstones, but from the Permian onwards to early Miocene sedimentation was continuous and in general terms remarkably constant, the deposits formed being dominantly calcareous. Thick limestone formations alternated with marly limestones or limy shales and, locally, reef limestones were formed, flanked by more bathyal conditions. At intervals, particularly in Jurassic, Cretaceous and Eocene, foul bottom conditions resulted in the deposition of black sulphurous limy muds which on consolidation became the polybituminous marls and marly limestones thought to be the source rocks of the oil. At intervals also, particularly towards the Arabian shore of the Gulf, lagunar conditions alternated with normal marine, resulting in anhydrites being interbedded with limestones and marls at a number of levels in Triassic, Jurassic, Cretaceous, and

FIG. 1.—*Generalised Geological Map of Iran, Iraq and the Persian Gulf Region, showing location of oilfields.*
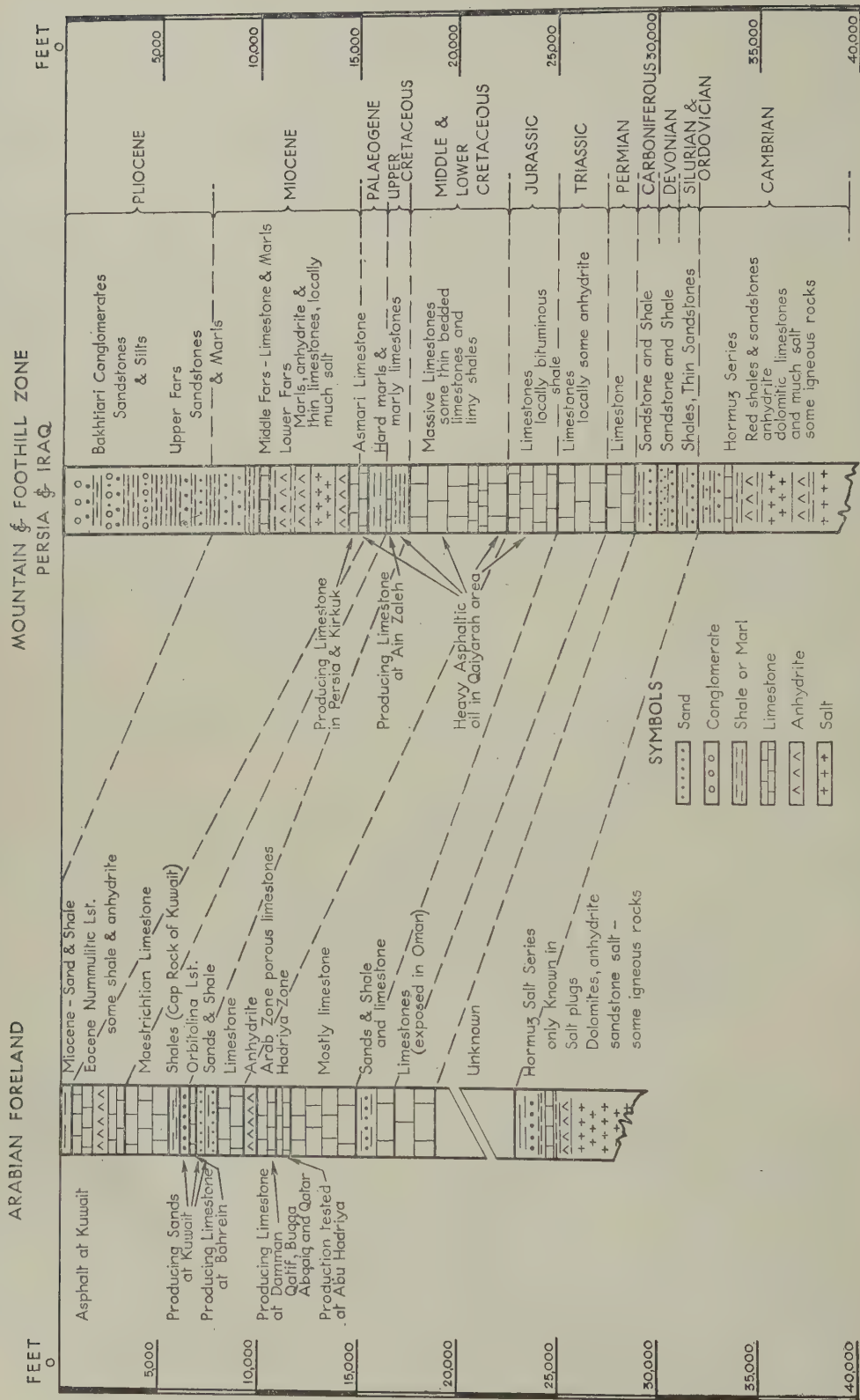
Fig. 2.—*Generalised Table of Strata showing correlation between Mountain Front and the Arabian Foreland.*

Eocene. In the Middle Cretaceous some areas, Kuwait and western Iraq for example, received sandy material washed down from the granitic hills of Central Arabia.

The first great change in sedimentary conditions, after this prolonged dominantly lime-depositing period, began in Oligocene and Lower Miocene; gentle warpings and undulations caused shoal areas in some places and concentrated lagunar conditions in others. Extensive evaporite deposits, the Lower Fars series, locally attained many thousands of feet in thickness of alternating anhydrites, salt and marls. This lagunar phase was ended before the end of the Middle Miocene by a return to normal marine conditions, but after a short time the sea withdrew and throughout the Upper Miocene and Pliocene a great thickness of marls and sandstones, the Upper Fars, and of silts, sandstones, and conglomerates, the Bakhtiari series, were deposited in the great synclines then in slow process of development. Towards the Arabian side, on the other hand, the greater rigidity prevented the formation of such synclines and basins and consequently further deposition of sediments was halted, or nearly so; the Oligocene is missing here, the Miocene is represented by only a few hundred feet of sandy marls and no Pliocene deposits have been recognized.

The contrast between the sedimentary sequence along the Iraq-Persian mountain front and that of the Arabian foreland is clearly shown in Fig. 2, but it will be seen that the greatest difference is in the attenuation of Miocene and Pliocene sedimentation on the Arabian side. The gradual shift of the geosynclinal axis towards the foreland which is such a common feature along the Alpine system did not occur in this instance. The thickness of Mesozoic and Eocene sediments deposited along the Arabian oilfield zone was as much as, or locally more than, the average along the strongly folded Persian mountain front, but in Neogene times the greatest subsidence, allowing the accumulation of 10,000 to 20,000 feet of sediments, occurred along what is now the foot-hill belt in front of the mountain ranges.

The compressional movements of the Pliocene directed from the thrust fronts of Central Persia towards the Arabian massif produced a pattern of great mountain anticlines of unusual dimensions and regularity. The north-easterly zones are locally more strongly compressed and faulted, but, notwithstanding many exceptions, the dominant feature is simplicity. Several anticlines have lengths of 200 to 250 miles and many 100 to 200 miles. The straightness of these great fold lines indicates an unusual regularity and constancy of the compressive force. The mountain anticlines mostly expose Cretaceous and Jurassic limestones, but towards the south-west the structural elevation of the anticlines decreases and in the foot-hill zone the Palaeogene and Cretaceous limestones still have a cover of softer and plastic strata of the Miocene and Pliocene. It is in this zone that the oilfields of Iraq and South-west Persia are situated.

The structural simplicity of the folded zone applies only to the competent limestone groups and not to their cover of Lower Fars series. The salt content of this series has occasioned a structural disharmony of a very unusual type between the Lower Fars and higher formations and the Asmari Limestone. In consequence of the large-scale sliding of these upper groups and of the squeezing out of the Lower Fars salt, surface synclines may overlie Asmari limestone anticlines and vice versa. This problem is the subject of a separate paper by C. A. E. O'Brien.

The outline map (Fig. 1) shows how the oilfields in the foot-hill zone fall into two groups—Kirkuk and Naft Khaneh/Naft-i-Shah to the north-west, and Lali, Masjid-i-Sulaiman, Haft Kel, Agha Jari and Gach Saran to the south-east. Between them there is the great mountain culmination of Pusht-i-Kuh with the two oilfield groups lying in structural embayments, the Sirwan* embayment to the north-west and the Diz-Karkheh* to the south-east.

Morphologically the Pusht-i-Kuh mountains appear at first sight to be a fold arc but structurally they are not so; the component anticlines of which they are formed pitch down into and cross the embayments with remarkably little swing in direction, and a study of Cretaceous and Eocene facies

---

* Named after the prominent rivers draining into these embayments. In its lower reaches the Sirwan river is known as the Diyala.

lines and isopachytes shows no simple relationship between present form and palaeogeography. The Pusht-i-Kuh is, therefore, not a fold arc but a fold culmination. It is also not a transversal, as the high mountain ranges are formed in the main by two major anticlines behind which, to the north-east, is a series of lower folds. No transversal system of culminations can be traced nor does a study of palaeogeography indicate such an effect.

To the south-east of Gach Saran, there is a bulge forward of the mountain anticlines to the Persian Gulf coast south-east of Bushir. Between Lingeh and Bandar Abbas there is a marked swing in the general strike direction to east—north-east clearly influenced by the impact of the Pliocene fold pattern on the resisting buttress of the Musandain peninsula of Oman. The Oman ranges of Arabia have had an unexpected structural history in that they were intensely compressed and thrust during the important phase of movement in pre-Maestrichtian Upper Cretaceous time (Lees, 1928). This phase affected the more north-easterly zone of the Persian-Iraq mountain system but not the outer fold zone now under discussion.

The north-south pre-Maestrichtian folding of Oman formed mountains of basic igneous rocks and radiolarian cherts, detritus from which was probably carried into the adjacent shallow sea to the west during Maestrichtian and Eocene. The effect of the Oman folding was felt for a considerable distance west of the mountain ranges and influenced the strike direction of Qatar and Bahrein. Slight effects of gentle pre-Maestrichtian movement have been recorded from drilling results even as far west as Kuwait.

The zone containing proved or possible oilfields extends from the entrance to the Persian Gulf to the Turkish frontier north of Mosul, and perhaps beyond, a distance of 1,200 miles, and its breadth from the mountain front to the Arabian fields is about 250 miles. This breadth from mountains to foreland is much greater than the average along the Alpine mountain system as a whole, along parts of which, Bavaria, for example, there is little or no folded zone between the thrust front and the rigid foreland. The great width of the folded zone of Iraq and Persia is one of the important factors contributing to the number and size of the oilfields. It would seem as if the thick skin of sedimentary rocks became detached from its rigid basement and folded into these long simple wrinkles, at least along the mountain front. Perhaps the Cambrian salt series has supplied the lubrication permitting this freedom of movement just as the Jura Mountains owe their present form in part to the lubricating quality of the Triassic salt.

The anticlines of the Arabian coastal zone are broad and gentle, and contrast strongly with those of the Zagros foot-hill ranges. The Arabian brachy-anticlines are mostly poorly exposed, but where there are outcrops or where their form has been explored by seismic surveys or by drilling, the flanks rarely exceed five degrees in dip and are more commonly only one or two degrees. But, notwithstanding such gentle dips the size of these anticlines is very great, for example Abqaiq, the largest of the Saudi Arabian fields, is 14 miles long by 5–6 miles wide with 1,400 feet of closure. Anticlines of this size are capable of effecting a concentration of oil on an impressive scale. It is possible that the structures in the Arabian coastal zone may have been influenced in their growth by movements of Cambrian salt, and some of them may in reality be the domal effects of non-piercement salt plugs. The islands in the Persian Gulf to the east of the Qatar Peninsula are salt plugs, as are some hills along the Trucial Coast. To the north-west of this area of intrusive plugs there is a considerable interval in which none are known—until the isolated hill of Jebel Sanam in Iraq, close to the Iraq-Kuwait frontier. Jebel Sanam is made of great masses of steep-dipping anhydrite and hard limestones, unfossiliferous dolomites, associated with altered igneous rocks, all very reminiscent of the Cambrian rocks usually associated with the Hormuz salt, though in this case no salt is exposed.

The oilfields along the Zagros foot-hill zone in Iraq and in Persia have one common factor, namely excellent cover rocks. The plastic salty marls and anhydrites and the salt of the Lower Fars series form an effective impervious seal to whatever limestone may immediately underlie it. The exact age of the reservoir limestone is not important. At Kirkuk, there is a change in the age of the producing limestone along the 60-mile length of the oilfield from Lower Miocene and Oligocene at the south-east

end to Middle Eocene at the other end, and yet this limestone functions as a continuous physical unit with, as a common factor throughout, the continuous cover of the Lower Fars.

The reservoir rock of the Persian fields is the Asmari limestone of Lower (perhaps Middle) Miocene to Oligocene age and averaging about 1,000 feet in thickness. Under conditions of steep folding the limestone is considerably broken and fissured, and if it had not been for the excellence of the Lower Fars cover rocks the oil content of these great reservoirs would undoubtedly have been lost by secular hæmorrhage; exploration drilling has proved that even the smallest exposure of the reservoir rock is sufficient to exhaust a major anticline of its oil content. In the Kirkuk and Masjid-i-Sulaiman fields the Lower Fars cover has been reduced by erosion to under 1,000 feet over the anticlinal summits.

Drilling experience in the Persian fields has also shown that the Lower Fars is not only the cover rock for the Asmari limestone itself, but it is the only effective barrier to upward migration of fluids which have come up from below through many thousands of feet of limestone, marly limestone and marls. Deep wells in both the Masjid-i-Sulaiman and Haft Kel oilfields have shown that the Middle Cretaceous limestone carries water in its fissure system, although cores of the limestone still contain impressive showings of oil in pores and cavities. This limestone, itself of considerable thickness, is separated from the base of the Asmari limestone by marls and marly limestones of Eocene and Upper Cretaceous age, which are 2,000 feet at Masjid-i-Sulaiman and 1,000 feet at Haft Kel. These strata, though themselves dense and impervious, have apparently been sufficiently cracked and broken by the folding movements to allow vertical fluid movement, and the Asmari limestone has thus become the reservoir for upward migrating oil derived from many thousands of feet of lower strata. The oil trapped under the impervious Lower Fars may have a multiple source, as possible source rocks in the form of polybituminous marls or limy shales occur at intervals through the Palaeogene, Cretaceous, and Jurassic, and even the Triassic, Permian, and lower Palaeozoic may have supplied a quota.

Cover rock and reservoir rock conditions in the Arabian fields are strikingly dissimilar to those along the Iraq and Persian mountain front. The gentleness of folding on the Arabian foreland has not made such demands on cover rocks, and thin groups of shale or of anhydrite are sufficient to form effective barriers to upward migration and to allow an oil concentration if a porous limestone or sandstone is present immediately below.

The Burgan field in Kuwait is a striking example of the small thickness of cover rock required under conditions of extremely gentle folding. The reservoir rocks at Burgan are separated from an upper group of limestones by the Cap Rock Shales which are reduced to just under 100 feet in thickness on the crestal part of the structure, thickening to over 200 feet down the flanks. Overlying these shales, which are probably of Turonian or Cenomanian age, there are almost continuous limestones of Maestrichtian and Eocene age from 3,600 feet depth to the surface, with only subsidiary amounts of shale and anhydrite (Fig. 3 and Barber, 1948, p. 89). These limestones are locally traversed by solution channels and are water-bearing. Some wells have had repeated losses of mud circulation on drilling through them; they also contain considerable amounts of asphalt and sulphur and there is an extensive surface asphalt deposit at Burgan which has been fed by thick oil escaping from these limestones. Yet the 100-foot Cap Rock Shale is sufficiently effective to contain and preserve one of the largest single oil accumulations known anywhere in the world.

The Burgan oilfield is exceptional among the Middle East fields in that its reservoir rocks are sandstones, whereas all other fields developed up to now produce from limestone reservoirs. It is a curious commentary on the lavishness with which Nature has designed the circumstances of this great oilfield province that in a dominantly limestone region a sandstone development of such exceptional quality should appear. The Burgan sands occur just above and below a thin Orbitolina limestone of Cenomanian age. The sands are exceptionally thick, porous, and permeable, and the great size of the field and the high producing rates of individual wells (up to 9,000 barrels per day) are the results of these favourable factors. There are four sand zones distributed through about 1,300 feet of strata but the bottom, or fourth, sand has not been fully penetrated as the oil-water level passes through it. The third and fourth sands are the most important, the former being 200 to 250 feet in thickness, and the

latter has 450 feet of oil sand above the bottom water. Only subsidiary amounts of shale are present in these great sand bodies, and there are also subsidiary sands in the more shaley interval of 150 feet separating them.

The Cenomanian sands of Kuwait must have been derived from the crystalline rocks of Central Arabia, the same source as has supplied the material for the desert sands of Egypt, Sinai, Palestine, and Southern Arabia. An omnibus name, the Nubian Sandstone, has been applied to these thick sandstone formations where control of age is lacking, but where marine shale or limestone intercalations are present it is possible to subdivide the Nubian into members of various ages. In Egypt there are sandstones of Upper Cretaceous, of pre-Cenomanian, and of pre-Carboniferous age. In Transjordan the sandstone is of pre-Cenomanian age, and there are local developments of Jurassic, Triassic, and Cambrian marine intercalations within the main sand body. In north-western Iraq near Rutbah, there is a sandstone development of about Cenomanian age, and in Dhofar in Southern Arabia there is a single thick sandstone lying between basement rocks and transgressive Cenomanian.

The name " Rutbah Sand " has been proposed for the Burgan oil sands (Barber, 1948, p. 90), but it is preferable to await vertical exploration of the whole series by drilling before deciding on a suitable name, if indeed one is required in addition to an age designation. In general the writer is opposed to local formational names where they can be avoided by using an age description.

The oilfields of Saudi Arabia, Bahrein and Qatar produce from limestone reservoirs at various levels between Cenomanian (Bahrein) and Jurassic (Qatar). The reservoir rocks are porous limestones, and the cover rocks are thin shales or anhydrite beds or zones interbedded with the limestones. The gentle folding and infrequency of faulting have allowed these thin shales and anhydrites to function as cover rocks in some cases, though in other cases apparently not. Thus the main Bahrein reservoir rock is an Orbitolina limestone of Cenomanian age. In the neighbouring anticline to the east, the Dukhan anticline on Qatar peninsula, this limestone carries water and the first oil production was met in some porous streaks in an Upper Jurassic limestone under an anhydrite cap. This horizon at Bahrein is gas-bearing.

In the Saudi Arabian fields the reservoir rocks are porous oolitic and dolomitic limestones in the Upper Jurassic, known collectively as the Arab zone, of 300 to 400 feet thickness and divided into
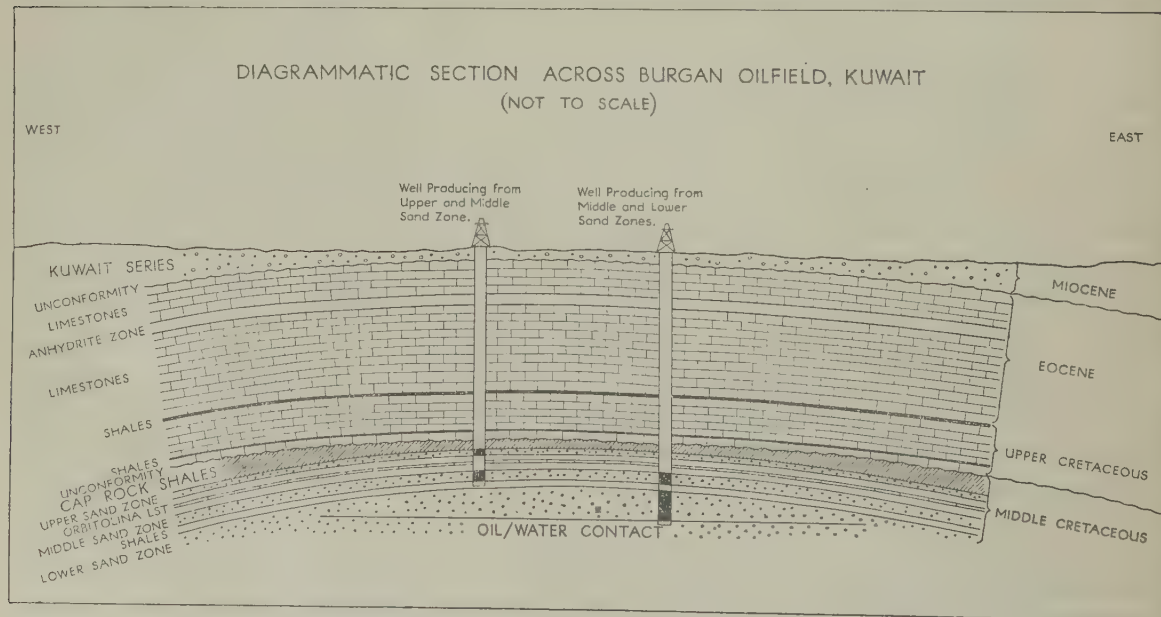

FIG. 3.—*Diagrammatic Cross Section of the Burgan Oilfield, Kuwait.*
(Not to scale, but with vertical exaggeration.) From BARBER, C. T., *Review of Middle East Oil*, 1948.

A, B, C, and D members, the members being separated by anhydrite beds. At Damman, the first field to be exploited, the Orbitolina limestone yielded only heavy oil, but all four members of the Arab zone are productive of good quality crude; elsewhere this is less common. At Abqaiq the A and B members are water-bearing, the C member yields a heavy oil used for road dressing, and the main productive horizon is the D member (Barber, 1948, pp. 76–77). At Abu Hadriya the Arab zone is water-bearing throughout, but oil production was found at a depth from surface of 10,200 feet in lower Jurassic limestones.

It is difficult, owing to inadequacy of published information, to analyze these varied results, but it would seem that the failure of certain horizons in some fields and their productivity in others is due to the competence or otherwise of the individual cap rocks. The distribution of heavy asphaltic oil is another puzzling feature. In the Burgan field and in some of the Arabian fields there is a marked increase in gravity of the oil close to oil-water level, an increase from a normal of about 0·86 S.G. to nearly 1·0. A small increase is common in many oilfields, but such an increase as this is very unusual and is difficult to explain. One possible explanation is that there are crudes of widely differing original character from different sources which have migrated into a common reservoir, and been inadequately mixed.

The degree of vertical migration postulated for the Persian oilfields has already been described, and in those cases there may have been a multiple origin for the Asmari oil. In the case of the Arabian fields the freedom for vertical migration is more restricted but there may, nevertheless, have been enough to cause a mingling of crudes from different sources. The extensive heavy oil shows in the Maestrichtian and Eocene limestones of Kuwait indicate substantial leakage at some time in the past of an oil much heavier than the present reservoir crude. The alternative, that the heavy oil has been " weathered " meets many difficulties of explanation, particularly when deep zones of heavy oil are considered such as at Abqaiq.

In Iraq, the Kirkuk field yields a crude oil of 0·85 S.G. with 2 per cent of sulphur, whereas at Qaiyarah, only 27 miles away across the strike, there is a change in oil character to a heavy asphaltic oil of 0·95 S.G. with 6 to 8 per cent of sulphur. This heavy oil has been found in the Qaiyarah vicinity throughout a range of formations from the surface to, and including, the Triassic. The Qaiyarah crude, however, is not a weathered product which has lost its light ends, for it still contains a surprisingly high proportion of tops—about 20 per cent of benzine and kerosene fractions, indicating that it may be a mixture of a light type of crude with a highly asphaltic and sulphurous type.

Exploratory drilling is now active throughout extensive areas in Syria, Iraq, Persia, and Arabia, and doubtless many new geological surprises lie in store. The area as a whole is, however, one of unusual geological uniformity throughout a fold belt of over a thousand miles in length. The foreland areas lying mostly under alluvium or desert sands are naturally less known, although drilling has already revealed the presence of regional highs, or Schwellen, and basins. The outstanding feature of the entire region, fold belt, and foreland alike, is the astonishing oil richness. The giant size of the anticlines, the excellence of the reservoir rocks and the competence of the cover rocks would avail little were it not for original oil richness, and this and the other factors in favourable conjunction are responsible for the great importance of the Middle Eastern oil province.

REFERENCES

BARBER, C. T. 1948. *Petroleum Times Review of Middle East Oil.*
LEES, G. M. 1928. The Geology and Tectonics of Oman and of parts of Southeastern Arabia. *Quart. Journ. Geol. Soc.,* 84, pp. 585–670.
———— and RICHARDSON, F. D. S. 1940. The Geology of the Oil-Field Belt of S.W. Iran and Iraq. *Geol. Mag.,* 77, 1928, pp. 227–252.

THE STRATIGRAPHY OF THE MAIN PRODUCING LIMESTONE OF THE KIRKUK OILFIELD*

By F. R. S. HENSON

Great Britain

ABSTRACT

The Kirkuk anticline in North Iraq trends 50° W of N for some 62 miles.

Its oil reservoir is part of a fringing or barrier-reef belt ranging in age from Middle Eocene to Miocene, and trending 65° W of N for about 250 miles, with shorelines to the NE of Kirkuk. Owing to divergence between the trends of reef-belt and anticline, an axial NW-SE section along the latter shows in oblique direction the passage of contemporaneous deposits from shoreward (reef) to basinward (globigerinal) facies.

Petrographical and micropalaeontological characters of the successive facies-zones are as follows:—

(1) *Back-reef shoal zone;* hard, porcellanous limestones made up of lime-cemented calcareous muds and sands with elements of reef debris, etc., well-rounded by surf action; Miliolidae and Peneroplidae abound with some coral and algal patches.

(2) *Reef-zone;* hard, porcellanous, un-bedded limestones of extremely irregular lithology, with large colonies of corals and algae; Rotaliidae are characteristic.

(3) *Fore-reef shoal zone;* porous or lime-cemented, micro-detrital limestones composed of calcareous debris of reefs and indigenous organisms, the elements being angular because deposited below the range of breaker erosion; echinoids, Nummulitidae and Orbitoididae are abundant; some algal patches may occur.

(4) *Basinal zone;* globigerinal limestones and marls.

Palaeontological correlations show that the reef-belt migrated, with some fluctuation, from NE to SW, so that each facies-zone cuts upwards across time-planes in that direction. Facies changes are gradational in vertical and horizontal sequences.

Reef studies in the Middle East suggest that oil may be generated in protected depths on the basinal side of a reef; that porous fore-reef limestones may serve as source and carrier beds; and that irregularities in the reef itself may provide stratigraphic traps until folding and fracturing distribute oil throughout the reef reservoir.

---

* For joint discussion of this and other papers see pp. 68-73.

THE ASMARI LIMESTONE OF SOUTH-WEST IRAN*†

By A. N. THOMAS
Iran

ABSTRACT

The bulk of Iran's production of crude oil is obtained from the Asmari Limestone formation. In the type succession at Kuh-i-Asmari in Khuzistan, the formation is 1,030 feet thick.

The underlying *Brissopsis* Beds (115 feet) and Basal Anhydrite (20 feet) are included in the Asmari Limestone formation in current oilfield terminology. At Gach Saran oilfield the limestone is·1,600 feet thick, but the lower part correlates with beds underlying the Asmari Limestone at the type locality and with the Khamir Limestone of Oligocene age in the Bandar Abbas district. The upper part of the type succession correlates with the Kalhur Limestone of the Khanaqin district. Lateral variation and correlation is discussed and summarized in a facies/time diagram, and it is concluded that the term Asmari Limestone formation in the wide sense should include the *Brissopsis* Beds, the Kalhur Limestone and probably also the Khamir Limestone.

Certain parts of the Asmari Limestone were laid down in environments believed to be suitable for oil formation, and·the organic content of the sediments was probably adequate to account for the present oil accumulation. Other highly foraminiferal parts of the limestone were deposited under conditions unsuitable for oil formation.

INTRODUCTION

APART from a small production from Eocene thin-bedded limestones at Masjid-i-Sulaiman, the whole of Iran's production of crude oil is obtained from a thick limestone formation known as the Asmari Limestone.

References to the age of the limestone in existing literature are conflicting. Busk and Mayo (1918) used the term " Asmari Series," which they regarded as " Eo-Cretaceous " (meaning Cretaceo-Eocene), for a massive " Nummulitic " limestone which they termed the " Asmari Limestone " and the underlying shale group. They observed (1918, p. 17) that the fossil evidence indicated a Middle or Upper Oligocene age for the Asmari Limestone. The term " Asmari Limestone Series " was used by R. K. Richardson (1924), who designated Asmari Mountain as the type locality, and correlated it with the Oligocene Khamir limestone (1924, p. 263), but the succession at Asmari Mountain is unfortunately omitted from his correlation diagram. H. de Böckh, G. M. Lees, and F. D. S. Richardson (1929, p. 102) defined the Asmari Limestone as Lower Miocene and excluded the Oligocene " *Brissopsis* Beds " at Asmari Mountain. They point out that, although the lower part of the Asmari Limestone may be Oligocene, the Khamir Limestone is older than the Asmari proper. Current oilfield practice includes the " *Brissopsis* Beds " in the Asmari Limestone since the Basal Anhydrite is a more definite marker than the change from Asmari Limestone proper to the marly limestones of the " *Brissopsis* Beds " (Lees, 1933). M. Reichel (1936-37, p. 110) suggests that the upper part of the Asmari Limestone may be of Helvetian age. R. Furon (1941, p. 352) refers the " Asmari Series " to the Stampian, Aquitanian, and Burdigalian. F. G. Clapp (1940, p. 75) puts the " Asmari " in the Aquitanian, which he regards as Oligocene.

This note is made possible by the work of the geologists of the Anglo-Iranian Oil Company (formerly Anglo-Persian Oil Company) during the last 35 years. While acknowledging the very considerable debt to previous and contemporary workers, the author alone must accept responsibility for the
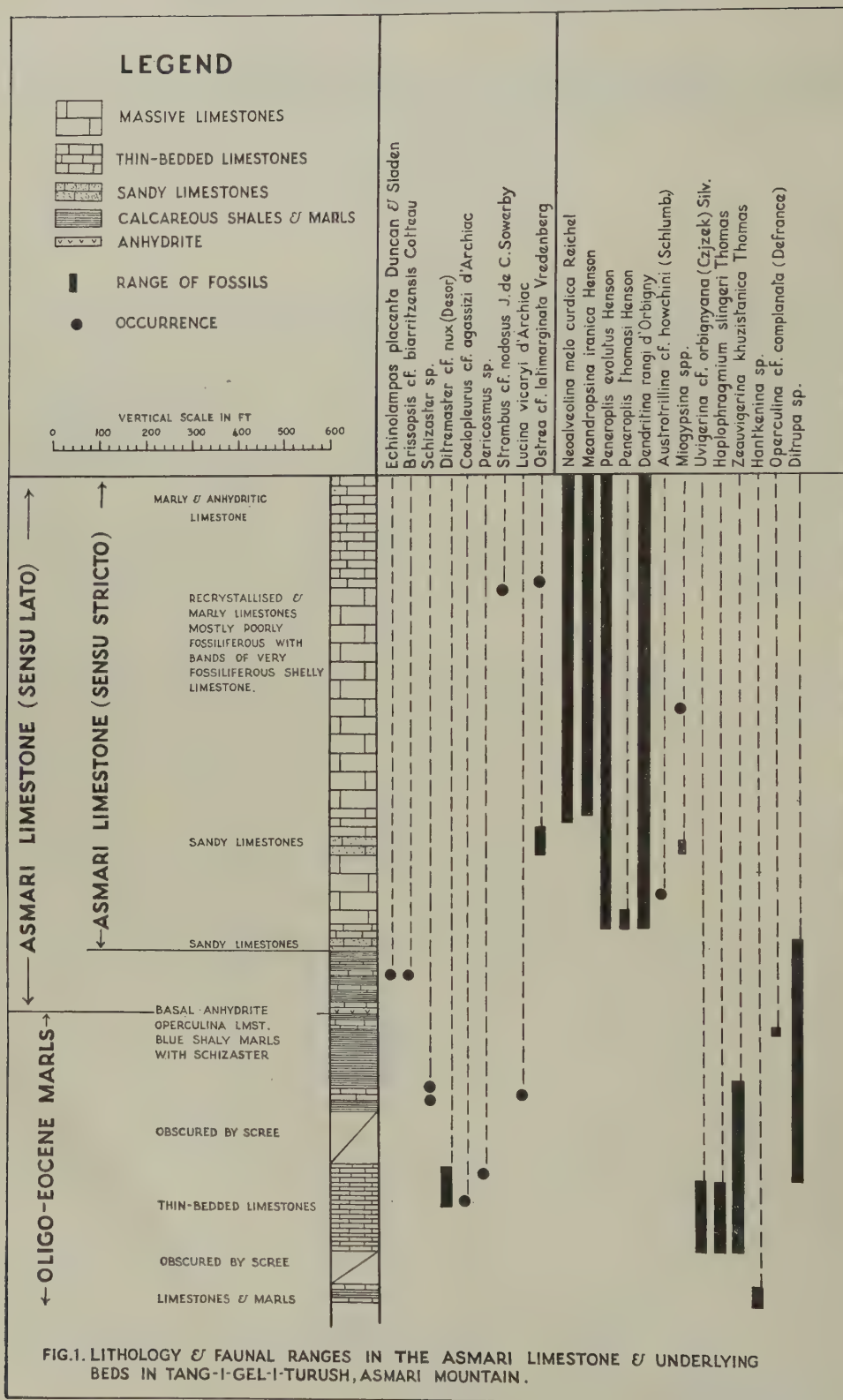

FIG.1. LITHOLOGY & FAUNAL RANGES IN THE ASMARI LIMESTONE & UNDERLYING BEDS IN TANG-I-GEL-I-TURUSH, ASMARI MOUNTAIN.

accuracy of information and opinions expressed. The author has to thank Dr. G. M. Lees, Mr. P. T. Cox, and Mr. J. G. Child for constant encouragement and helpful discussion. Mr. F. R. S. Henson has kindly permitted the author to make use of the names of several new species of the Peneroplidae which are in course of publication by him (Henson, 1950); these are marked throughout with an asterisk.

THE TYPE SUCCESSION

The type succession at Asmari Mountain has recently been measured and sampled at 5-foot intervals throughout by the author at Tang-i-Gel-i-Turush near the crest maximum of the anticline. Examination of thin sections of all samples under the microscope makes possible a more detailed subdivision than that already published (Böckh, &c., 1929, p. 102). The general succession is illustrated in Fig. 1, which also indicates the ranges of the more important elements in the fauna. The macrofossils, with the exception of *Ostrea* cf. *latimarginata* Vredenburg, were identified by J. A. Douglas from collections made in 1924 by L. V. A. Fowle. The microfauna has been identified by the author.

The succession at Asmari Mountain falls into the following subdivisions:—

	Feet
8. *Neoalveolina* Beds	750
7. Sandy limestones with *Miogypsina*	70
6. Shelly and Miliolid Limestones	210
Asmari Limestone (*sensu stricto*)	1030
5. *Brissopsis* Beds	115
4. Basal Anhydrite	20
Asmari Limestone (*sensu lato*)	1165
3. Calcareous shales with *Schizaster*	210
Obscured by scree	100
2. Thin bedded white limestones and bituminous marls with *Ditremaster* cf. *nux.* (Desor) and *Haplophragmium slingeri* Thomas	190
Obscured by scree	70
1. Marls and Limestones with *Hantkenina*	40 (exposed)
Oligo-Eocene " Marls "	610

1-3. The Oligo-Eocene " Marls " are a series of calcareous shales, marls, and marly limestones with some glauconitic bands with a restricted fauna of Globigerinidae, Anomalinidae, and Textulariidae of non-diagnostic character. An Eocene age is indicated by the *Hantkenina* sp. at the base and a Lower Oligocene age by the *Haplophragmium slingeri* Thomas in group 2. The thin-bedded limestones are traversed by thin calcite veins containing manjak.

At 35 feet below the Basal Anhydrite there is a distinctive bed 1 foot thick crowded with *Operculina* cf. *complanata* (Defrance) and bryozoa.

4. The Basal Anhydrite is a remarkably constant bed of pure anhydrite, partly weathered to gypsum at the surface, with some thin dolomitic limestones interstratified in its lower part. Immediately above it there is a thin sandy limestone with abundant gastropod, lamellibranch and ostracod remains.

5. The *Brissopsis* Beds are a series of blue marls and thin yellow marly limestones for which an Oligocene age is suggested by its macrofauna. The microfauna is non-diagnostic, consisting of Globigerinidae, dwarf Miliolidae, and Anomalinidae, with *Tubucellaria* sp. and *Membranipora* sp.

6-8. The Asmari Limestone (*sensu stricto*) is 1,030 feet thick, and is usually a hard compact limestone weathering cream or brown in colour. Freshly broken surfaces often have a faint pink and white mottled appearance. White marly bands sometimes appear, and these are often anhydritic especially

FIG. 2. LITHOLOGY & FAUNAL RANGES IN THE ASMARI LIMESTONE & UNDERLYING BEDS AT TANG-I-GURGUDA NEAR GACH SARAN.
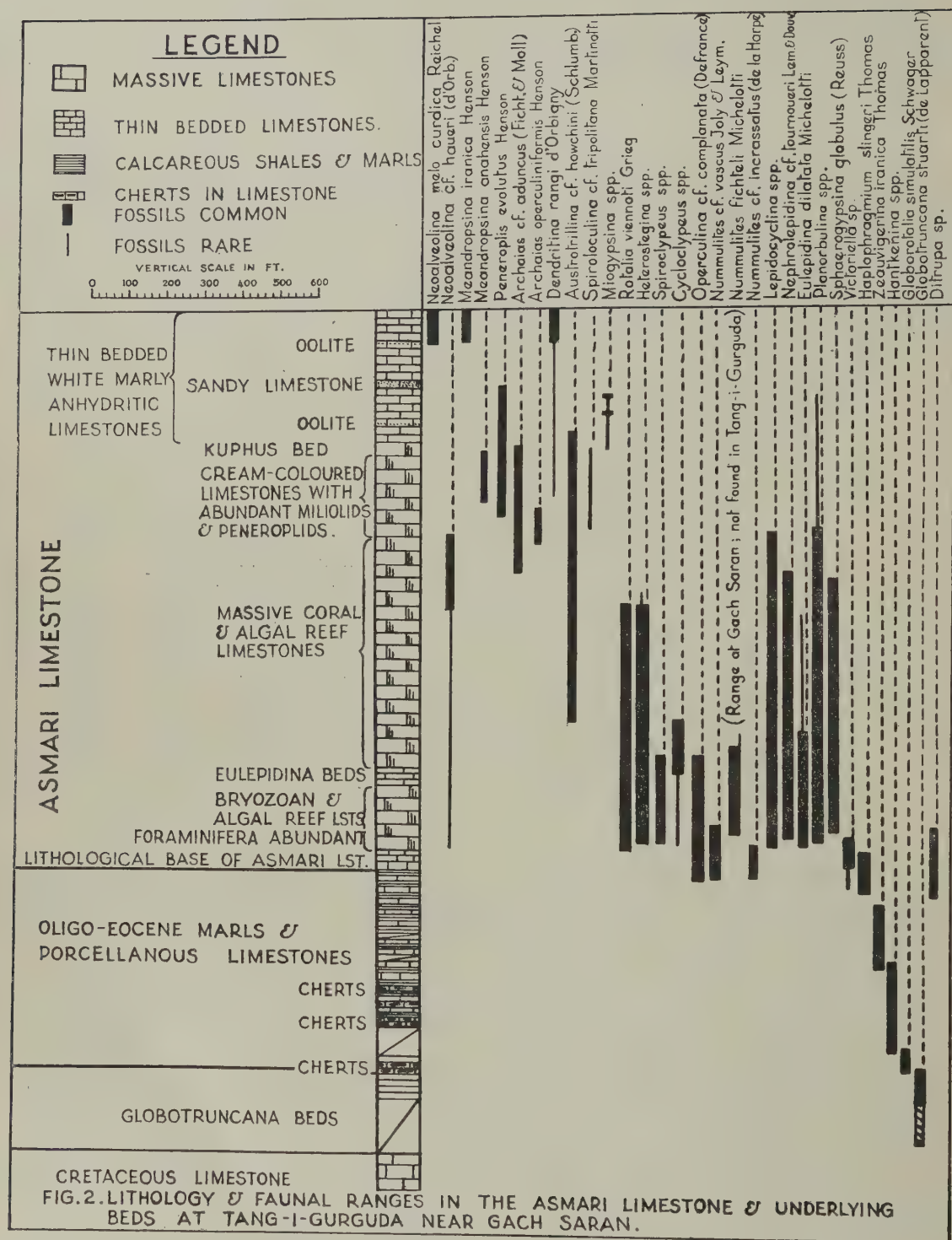
FIG. 2.

near the top of the formation and immediately below the *Miogypsina* beds. Very shelly bands are frequently intercalated, but it is rarely possible to extract specimens suitable for identification.

The limestone is usually very much recrystallized, porous, and well jointed. Although it is such a prolific reservoir of oil in the buried anticlines few traces of the former presence of oil can be detected in the main mass of the exposed Asmari Limestone.

6. Shelly and Miliolid Limestones succeed the " *Brissopsis* Beds " and constitute a somewhat variable sequence. At the base are slightly sandy limestones with much echinoid debris, gastropods, Anomalinidae, Globigerinidae, *Ditrupa* sp., and *Tubucellaria*, *Membranipora* and other bryozoa. They are followed by more massive limestones which are usually much recrystallized, sometimes coarse, but more often very finely crystalline. Marly limestones with rare dwarf Miliolidae alternate with shelly limestones containing abundant echinoid debris, crab fragments, gastropods and lamellibranchs, recognizable in thin section but never yet found weathered out in a form suitable for identification. Miliolidae and *Dendritina rangi* d'Orbigny are common, but *Archaias* is absent, and a solitary occurrence of *Austrotrillina* cf. *howchini* (Schlumb.) is recorded in the upper part. This is a noteworthy point of difference from the " Miliolid Limestones " of the " Asmari Limestone " of some other areas of south-west Iran, in which *Austrotrillina* and *Archaias* are extremely abundant.

Towards the top of this group marly limestones contain crystals of anhydrite, and a patch of gypsum has been recorded in this position high up on the Asmari Limestone cliff. This corresponds with the anhydrites developed below the " Lower *Miogypsina* zone " in the wells at Masjid-i-Sulaiman (Lees, 1933, p. 234) and probably with the Kalhur Anhydrite (Lees, 1933, p. 240).

7. Sandy limestones with *Miogypsina* correspond with the " Lower *Miogypsina* zone " of the Masjid-i-Sulaiman oilfield (Lees, 1933, p. 234). The species of *Miogypsina* have not yet been identified but the association with *Ostrea* cf. *latimarginata* suggests a Burdigalian or Vindobonian age. Shelly limestones with echinoid debris, gastropods and lamellibranchs are abundant in this part of the formation.

8. The *Neoalveolina* Beds form the major part of the Asmari Limestone at Asmari Mountain, being 750 feet thick. South-west of Asmari Mountain the beds thin rapidly to about 330 feet at Haft Kel oilfield, but to the north they thicken to about 840 feet at Bard-i-Qamcheh. The characteristic fossils are *Neoalveolina melo* subsp. *curdica* Reichel and *Meandropsina iranica* Henson* associated with *Dendritina rangi* d'Orbigny and numerous Miliolidae and Anomalinidae. Echinoid debris is abundant throughout and occasional bands are rich in gastropods and lamellibranchs.

The limestones are often finely crystalline with all trace of organic remains destroyed. A curious feature is that the porcellanous foraminifera are very often crushed and distorted in some beds whilst the hyaline forms remain undamaged. Towards the top the limestones become more marly and anhydritic.

The *Neoalveolina* Beds are possibly of Helvetian age as suggested by M. Reichel, and I am informed by Mr. F. R. S. Henson that this concurs with his stratigraphical conclusions in the Middle East.

Upper Limit of the Asmari Limestone.—The lowest member of the Lower Fars group which overlies the Asmari Limestone is the " Cap Rock Anhydrite." This is concealed at Tang-i-Gel-i-Turush, but is found lying on top of the *Neoalveolina* Beds at the north-west and south-east ends of the mountain. At the junction a few feet of highly anhydritic limestones with nodules of gypsum and anhydrite are exposed in places. The Cap Rock anhydrite itself is a very distinctive rock 100 feet thick with a very characteristic structure which enables it to be easily recognized in thin section.

THE GACH SARAN DEVELOPMENT

The Asmari Limestone of the Gach Saran oilfield 120 miles south-east of Asmari Mountain is 1,600 feet thick, and has been studied in detail by Mr. J. G. Child, who distinguished six stages below the Cap Rock Anhydrite.

These stages with the palaeontology revised in the light of recent work are:—

6. Fine-grained hard compact recrystallized limestones with anhydrite nodules and lenses and thin beds of grey shale, with *Neoalveolina melo curdica* Reichel.. 130 feet

5. Coarse sandy limestones passing down into oolitic and pseudo-oolitic limestones with bands of grey shale. Anhydrite is developed throughout the stage.. 160 feet

4. Porous oil-impregnated limestones with a zone of *Miogypsinoides complanata* (Schlumb.) at the top, below which come beds containing *Peneroplis evolutus* Henson*, *Meandropsina anahensis* Henson*, *Archaias* spp. and *Austrotrillina*. Below them are 150 feet of limestones with anhydrites and then 120 feet of recrystallized limestones with the same fauna. The anhydrites may correspond with those below the *Miogypsina* beds at Masjid-i-Sulaiman.. 450 feet

3. Compact grey and brown limestones with *Neoalveolina* cf. *haueri* (d'Orb.) in the upper part. Corals and calcareous algae in abundance indicate that these are reef-limestones...................... 360 feet

2. Porous oil-impregnated limestones with corals, calcareous algae, lepidocyclines (including *Eulepidina dilatata* Michelotti), *Nummulites* cf. *fichteli* Michelotti, *Heterostegina* and swarms of *Rotalia viennoti* Greig. Near the base is an abundance of *Austrotrillina* sp., *Praerhapydionina delicatus* Henson* and *Archaias operculiniformis* Henson*....................................... 300 feet

1. Grey, marly, dense, fine-grained limestones with abundant corals, calcareous algae, bryoz a, echinoid fragments, *Rotalia* swarms, *Nummulites* cf. *vascus* Joly and Leym, *N.* cf. *incrassatus* (de la Harpe), *Cycloclypeus* and *Heterostegina*... 200 feet

Tang-i-Gurguda.—The author has sampled the Asmari Limestone and underlying beds at 5-foot intervals throughout the outcrop exposures at Tang-i-Gurguda about 12 miles north-east of Gach Saran, and the results of the palaeontological examination are illustrated in Fig. 2. The general succession is much the same as at Gach Saran, but the total thickness is reduced to 1,330 feet, and the various stages are correspondingly reduced.

The *Neoalveolina melo curdica* beds are anhydritic limestones only 80 feet thick. Below them are 120 feet of unfossiliferous marly anhydritic limestones, very sandy at the base, underlain by beds with *Miogypsina* down to about 340 feet.

From 340 feet to 600 feet is the *Austrotrillina-Meandropsina* fauna of the lower part of stage 4 at Gach Saran. Below it come coral and algal reef limestones crowded with *Heterostegina* and *Rotalia viennoti* and with *Neoalveolina* cf. *haueri* corresponding with stage 3 at Gach Saran. Well bedded limestones with *Eulepidina dilatata* correspond with stage 2 of Gach Saran, but in the outcrop section *Nummulites* cf. *fichteli* has not been found nor has *Praerhapydionina delicatus* Henson.* Stage 1 of Gach Saran is represented by bryozoan and algal reef limestones with abundant *Rotalia, Heterostegina, Cycloclypeus, Lepidocyclina* and *Nummulites* cf. *incrassatus* at the outcrop.

The lower 730 feet of limestone at the outcrop has a recrystallized matrix, and the calcite mosaic is much coarser than that of the recrystallized limestones in the higher part. Apart from solid reef limestone there is much consolidated reef detritus with broken foraminifera, shells, and algae.

CORRELATION AND LATERAL VARIATION

The type succession of the Asmari Limestone at Asmari Mountain and the development at Gach Saran can be correlated through a series of intermediate sections and exposures along the flanks of intervening major anticlines. The top of the formation is well defined by the junction with the "Cap Rock" Anhydrite. This bed extends for at least 300 miles and possibly as much as 500 miles along the strike and for 50 miles at right angles to the strike, and there is every reason to believe that where it is developed the junction with the underlying Asmari Limestone is at almost exactly the same time plane. This is based on the fact that a similar lithological and faunal sequence is found in many places in the Lower Fars formation overlying the "Cap Rock" whilst beds with *Neoalveolina melo curdica* Reichel invariably occur below it.

The *Neoalveolina melo curdica* beds are not definitely known south-east of Kuh-i-Dera, near Gach Saran, and in this region they are about 100 feet thick. They thicken to about 800 feet at Bard-i-Qamcheh, 30 miles north of Kuh-i-Asmari, but thin again to the south-west and north-west. At Naft Khaneh in north-east Iraq they form the whole of the local Asmari Limestone (the " Kalhur Lime-

stone ") which is only 245 feet thick. Further north at Kuh-i-Bishkan they are absent, but there are doubtful records of *Neoalveolina* in beds of Lower Fars (gypsum/marl) facies overlying the local Asmari Limestone. It may be noted that *Neoalveolina melo curdica* definitely occurs in the Lower Fars at Kirkuk (*vide* Henson).

Below the uppermost part of the Asmari Limestone there is a variable group of beds, usually containing a small species of *Miogypsina* and *Ostrea* cf. *latimarginata*. These beds are often very sandy as at Gach Saran, Agha Jari, Kuh-i-Pabda and the Sehzar Gorge. At the latter place and at the south end of Kabir Kuh and in many localities in the Bakhtiari country (*vide* Dr. A. Allison and Mr. F. C. Slinger) they are associated with pene-contemporaneous conglomerates. Anhydrite occurs as lenses and nodules at or just below the same level in Gach Saran, Agha Jari, Masjid-i-Sulaiman and other places, and corresponds roughly in position with the thick " Kalhur Gypsum " of Pusht-i-Kuh and Naft Khaneh. This variable group may be correlated with the Burdigalian.

The Lower Miocene (probably Lower Burdigalian and/or Upper Aquitanian) is represented at Gach Saran by Miliolid Limestones with *Meandropsina anahensis* Henson* associated with a facies fauna of *Austrotrillina* cf. *howchini* and *Archaias* spp.

This fauna is widespread in the Asmari Limestone at this level but is not found in the type succession, although a solitary *Austrotrillina* sp. has been found there. This genus however is a very common fossil in association with *Archaias* at many levels in the Asmari Limestone outside the type area from Aquitanian down to the lowest Oligocene. Correlation of the lower part of the Gach Saran development and the lower part of the type succession can be made only on general stratigraphical grounds at present.

The only distinctive micro-fossil found commonly in the Kuh-i-Asmari succession below the *Miogypsina* beds is *Haplophragmium slingeri* Thomas which is found at 350 to 500 feet below the Basal Anhydrite. The same species occurs immediately below beds with *Nummulites fichteli*, beds with *Eulepidina dilatata* and basal Asmari Algal/*Lepidocyclina* reef limestones in the surface exposures near Gach Saran, and in the same position at Bard-i-Qamcheh, Kabir Kuh, and Kuh-i-Bishkan. At Tang-i-Gurguda it is found rarely in the algal reef limestones themselves. This is a clear pointer to the correlation of the lower part of the Asmari Limestone of Gach Saran with the " *Brissopsis* Beds," the Basal Anhydrite and the shales with *Schizaster* at Kuh-i-Asmari.

This correlation is supported by the lateral passage of the Basal Anhydrite at the north end of Kuh-i-Bingistan through a cavernous crystallized limestone into the *Eulepidina* beds at the south end of Kuh-i-Bingistan. Between Kuh-i-Bingistan and Gach Saran lies Kuh-i-Khaviz from which locality Mr. E. J. White has collected *Eulepidina elephantina* Munier-Chalmas, *Cycloclypeus* and *Spiroclypeus*, indicating an Upper Oligocene age.

The Basal Anhydrite itself is a first-class marker and is already known over an area of approximately 3,500 square miles from surface exposures in Kuh-i-Asmari and other mountains, and from wells in the Lali, Masjid-i-Sulaiman (Maidan-i-Naftun), White Oil Springs and Haft Kel oilfields. In all probability the Lower Deh Luran Gypsum is at the same level, although there is as yet no palaeontological confirmation of this. If so, however, the Basal Anhydrite extends over more than 11,000 square miles.

The Basal Anhydrite may be regarded as correlating with the *Eulepidina* beds at Gach Saran; the overlying " *Brissopsis* Beds " correlate with the massive coral and algal reef limestones containing *Austrotrillina*, *Neoalveolina* cf. *haueri*, *Rotalia viennoti* and *Heterostegina*. Similarly the limestones above the " *Brissopsis* Beds " at Kuh-i-Asmari will correlate with the Miliolid-Peneroplid limestones at Gach Saran (*Archaias-Austrotrillina* fauna). The marls with *Schizaster* at Kuh-i-Asmari correlate with the bryozoan and algal reef limestones at the base of the " Asmari Limestone " of Gach Saran. At Kuh-i-Asmari these marls contain *Zeauvigerina khuzistanica* Thomas which is distinct from *Zeauvigerina iranica* Thomas occurring below *Haplophragmium slingeri* Thomas near Gach Saran. *Zeauvigerina iranica* Thomas is of Upper Eocene age, and its lower occurrences overlap with those of *Hantkenina* sp.
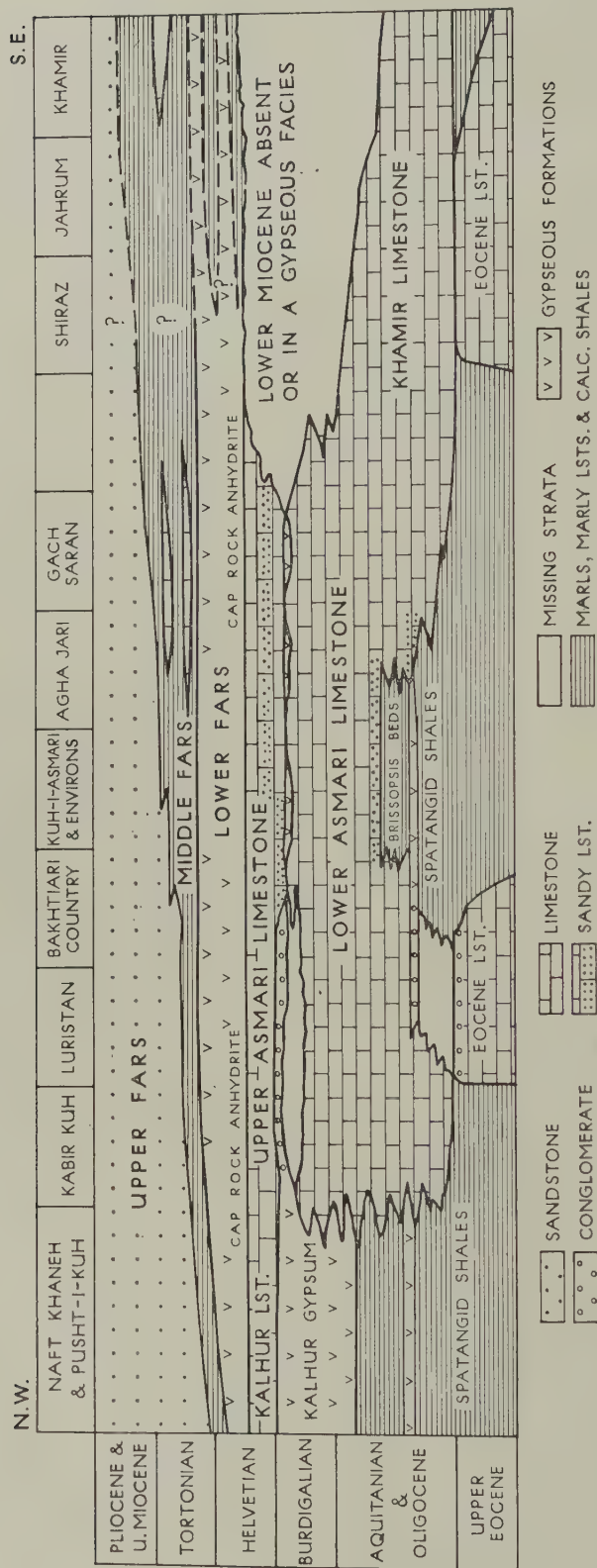
41

FIG 3. FACIES/TIME DIAGRAM OF THE ASMARI LIMESTONE & RELATED FORMATIONS IN S.W. IRAN

Lateral variation and correlation of the Asmari Limestone and related formations throughout south-west Iran is illustrated in Fig. 3. The lower part of the " Asmari Limestone " of Gach Saran is correlated on palaeontological grounds with the Khamir Limestone of the Bandar Abbas region, and with the lower part of the " Asmari Limestone " of Kabir Kuh and Luristan. In Luristan there are probably several lacunae in sedimentation represented by the conglomerates which are developed at various levels.

PETROLEUM IN THE ASMARI FORMATION

The nature of the Asmari Limestone as a reservoir rock for petroleum has already been described by Dr. G. M. Lees (1933). The mechanism of petroleum production from the Asmari Limestone formed the subject of the Redwood Lecture to the Institute of Petroleum by Mr. H. S. Gibson in March, 1948. The Asmari Limestone as a possible source of oil has been discussed by Dr. G. M. Lees (1934), and arguments in favour of the Asmari Limestone as a source rock were advanced by Mr. R. K. Richardson (1924).

The latter states (1924, p. 276) that the Asmari Limestone " is a highly organic rock composed almost entirely of foraminiferal remains," and favoured the decay of the organic matter as the most likely source of the oil.

The author records the following observations which have a bearing on the question of the Asmari Limestone as a source rock:—

(i) The Asmari Limestone includes several biofacies, as described by the author in a paper to Section " J " of this Congress. The proportion of organisms to total sediment and the nature of the organisms themselves varies considerably between the different facies. Certain parts of the Asmari Limestone, notably the reef limestones of Gach Saran, must have been laid down under well aerated bottom conditions. Other parts, such as the marly limestones of Asmari Mountain, could have been formed under quiet, rather saline, anaerobic bottom conditions. Although the percentage of organic remains is much less in the rocks laid down in the latter environment the conditions postulated were much more suitable for oil generation.

(ii) The Asmari Limestone of Asmari Mountain is not formed almost entirely or even mostly of foraminiferal remains. The calcareous remains of organisms may form up to 60 per cent of the limestone in this locality at certain levels, but the average is under 20 per cent, and large thicknesses of the rock are devoid of the remains of organisms. The barren rocks may be, in part, the result of recrystallization of the limestone which has completely destroyed the remains. On the other hand the barren rocks are often calcite mudstones and are associated with the development of anhydrite bands, nodules, or disseminations in the rock which indicate that the environment of deposition was not favourable, at times, to the existence of organisms.

(iii) The lower beds of the Asmari Limestone in the Gach Saran development are richly algal and foraminiferal reef limestones, with up to 85 per cent of the rock composed of calcareous remains. The constituent organisms, however, are mostly forms with heavily calcified tests, and it is uncertain what percentage of organic matter suitable for conversion to oil accompanied them. It was not necessarily very high.

The percentage of the remains of calcareous organisms in the Asmari Limestone is, however, not at all a true index of the former availability of organic matter suitable for conversion into oil. There may have been many organisms devoid of hard parts, and this applies particularly to algae other than the calcareous species so abundantly preserved as fossils. The possibility of organic material from terrigenous sources must also be considered, especially in the marly and sandy limestones which presumably include some sediment from the land. In some of the main Iranian fields the average porosity in the reservoirs is only 5 per cent to 6 per cent, and since oil-filled reservoir rocks are now only a small part of the Asmari Limestone formation as a whole, it may have required a very small percentage of organic matter in the original sediment to provide the present concentrations (cf. various authors, Illing, 1938, p. 35: " There is no need therefore to consider that petroleum source sediments need be abnormally rich in organic matter ").

The question of the relative abundance of organisms is considered to be of less importance than that of environment of deposition. The richly foraminiferal limestones of the Gach Saran development were associated with coral and algal reefs, and the aerated conditions associated with reef-building probably caused rapid oxidation and dispersal of any organic matter. The oil found in these limestones is almost certainly not indigenous. At Asmari Mountain and in the surrounding region, however, partially enclosed sea conditions, with the deposition of calcareous muds and anhydrite, and a restricted marine fauna, may be postulated from late Eocene to Middle Miocene times. Later on these conditions prevailed in the Gach Saran area also. Whether these conditions were associated with a lagoonal development on the margins of a sea or with the deeper central parts of a larger enclosed basin of deposition remains undecided, with arguments in favour of both hypotheses. But the important fact is that anaerobic conditions suitable for the generation of oil from organic matter present in the sea were probably present in this environment (cf. various authors, Illing, 1938, p. 35: " There are certain cases in shallow-water sediments where the sediments contain no free oxygen, and in the deeper parts of the sea this is the normal condition " *et seq*, and various authors, Trask, 1938, p. 42: " According to the prevailing opinion of geologists the chief mother substances of petroleum are organic compounds that accumulate in near-shore marine sediments in an environment deficient in oxygen "). In the author's opinion certain parts of the Asmari Limestone formation, particularly in the country around Asmari Mountain, were accumulated in such an environment. Later on in geological times the oil has migrated vertically and laterally into the more porous parts of the formation including the reef limestones and then into the structural highs.

A theory of formation of oil in the sediments of the Asmari Limestone of some areas does not exclude the possibility of the migration of other oil into the limestone from lower bituminous formations especially in other areas. This is especially so in relation to an oilfield like Gach Saran where the Asmari Limestone is mostly in a reef facies and the anhydritic calcareous muds, which the author associates with anaerobic conditions of deposition, are restricted to a small thickness in the upper part of the local development. The source of the oil must then be sought in earlier or contemporary sediments laid down under conditions more suitable for the generation of oil.

Bituminous shales and other oil indications exist at many pre-Asmari horizons in south-west Iran, and they are usually regarded as the most probable source of the Asmari oil. The author considers, however, that there is a case for considering the Asmari Limestones to be, at least in part, the source of the oil in some of its own reservoirs.

REFERENCES

DE BÖCKH, H., LEES, G. M., and RICHARDSON, F. D. S. 1929. Stratigraphy and Tectonics of the Iranian ranges. *In* GREGORY, J. W. *The Structure of Asia.*

BUSK, H. G., and MAYO, H. T. 1918. Some notes on the Geology of the Persian Oilfields. *Journ. Inst. Petr. Techn.,* 4, no. 17, p. 3.

CLAPP, F. G. 1940. Geology of Eastern Iran. *Bull. Geol. Soc. Amer.,* 51, pp. 1–102.

FURON, R. 1941. Géologie du Plateau Iranian. *Mém. Mus. d'Hist. nat.,* Nouv. Ser., tome vii, fasc. 2.

HENSON, F. R. S. 1950. *Middle Eastern Tertiary Peneroplidae (Foraminifera), with Remarks on the Phylogeny and Taxonomy of the Family.* Wakefield.

LEES, G. M. 1933. Reservoir Rocks of Persian Oilfields. *Bull. Amer. Assoc. Petrol. Geol.,* 17, no. 3, p. 229.

———— 1934. The Source Rocks of Persian oil. *World Petroleum Congress,* 1, no. 3, London.

———— and RICHARDSON, F. D. S. 1940. The Geology of the Oilfield Belt of South-west Iran and Iraq. *Geol. Mag.,* 77, no. 3, p. 227.

PILGRIM, G. E. 1908. Geology of the Persian Gulf. *Mem. Geol. Surv. Ind.,* 34, part 4.

———— 1925. The Geology of Parts of the Persian Provinces of Fars, Kirman and Laristan. *Mem. Geol. Surv. Ind.,* 48, part 2.

REICHEL, M. 1936-37. Etude sur les Alveolines. *Mém. Soc. Pal. Suisse,* 57 and 59.

RICHARDSON, R. K. 1924. The Geology and Oil Measures of Southwest Persia. *Journ. Inst. Petr. Techn.,* 10, p. 256.

THOMAS, A. N. 1949/50. *Haplophragmium slingeri* sp. nov. and some new species of *Zeauvigerina* Finlay from South-west Iran. (*Forthcoming publication in Ann. Mag. Nat. Hist.*).

Various authors. 1939. Classification and Nomenclature of Rock Units. *Bull. Amer. Assoc. Petrol. Geol.,* 23, no. 7, pp. 1068–1088.

Various authors. 1938. *The Science of Petroleum.* Oxford University Press.

TECTONIC PROBLEMS OF THE OILFIELD BELT
OF SOUTH-WEST IRAN*

By C. A. E. O'BRIEN
Great Britain

ABSTRACT

The extraordinary disharmony between the surface beds and the underlying oil-bearing Asmari Limestone, in South-west Iran, resulted from the mobility of the intervening, salt-laden Lower Fars Series. The following stratigraphical sequence is involved in a unique tectonic problem:

Fars-Bakhtiari	INCOMPETENT GROUP.
Lower Fars	MOBILE GROUP.
Pre-Fars	COMPETENT GROUP.
Cambrian Salt Series.	
Pre-Cambrian Basement	

During the Alpine Orogeny, forces set up by the movement of the Pre-Cambrian basement towards a possible orogen under the Central Iranian Plateau, were transmitted by friction to the controlling Competent Group. The formation of great anticlinal structures, within this group, produced forces within the overlying plastic series, which, following closely the laws of hydrostatics, resulted in the evacuation of salt from the high pressure areas over the rising crests, and its accumulation in adjacent synclines. Among examples of consequent disharmony, the resting of Incompetent Group synclines directly on the crestal areas of Asmari Limestone anticlines is of particular interest. Folding in the Incompetent Group was able to proceed to a " pseudo-competent " conclusion by virtue of the moulding and supporting action of the underlying plastic series.

These theories are discussed relative to the tectonic history of a representative area.

I. INTRODUCTION

IN a Presidential Address to the Geological Society of America, Professor Daly once remarked that the geologist, however specialized, had to be a courageous soul and venture where angels could not tread, and that to go down in imagination was an adventure, daring but thoroughly essential.

The oilfield belt of South-west Iran, by virtue of the remarkable disharmony of its folding, is certainly " out of bounds " to angels, and the study of its sub-surface geology provides adventure in full measure. So extraordinary is the disharmony between the Oligo-Miocene, Fars-Bakhtiari Series and the underlying Lower Miocene oil-bearing Asmari Limestone, that, in an area of 2,500 square miles, from Lali to Mamatain, between the Alluvial Plain and the Mountain Front (Fig. 1), the only places where the two series can be considered concordant are where parallelism of formations has occurred by chance. In Fig. 2 we show two typical examples of the wide divergence between the surface and underground structures, the reason for which has long been recognized to lie in the plasticity of the salt deposits near the base of the Fars-Bakhtiari Series.

The failure of the most careful surface stratigraphical mapping to reveal the position of underground Asmari Limestone domes has been a source of concern for many years. It appears inconceivable that a limestone dome 20 miles long, 7 miles wide, and with an amplitude of at least 10,000 feet, and at its crest maximum only 4,000 feet below the surface, could have been shaped as recently as Pliocene times and yet leave so little clue to its geographical position that it could only be located by geophysical methods. Yet such a dome was the present producing field at Lali, the axis of which was first defined in 1937 by a seismic refraction survey.

We believe, however, that successful geological interpretation of underground structure in South-west Iran will eventually be achieved by the study of the tectonic movements of the salt series, and of the effect of such movement on the overlying formations. In this paper we shall present a number of

---

OUTLINE MAP of TECTONIC GROUPS in SOUTH WEST IRAN

FIG. 1.
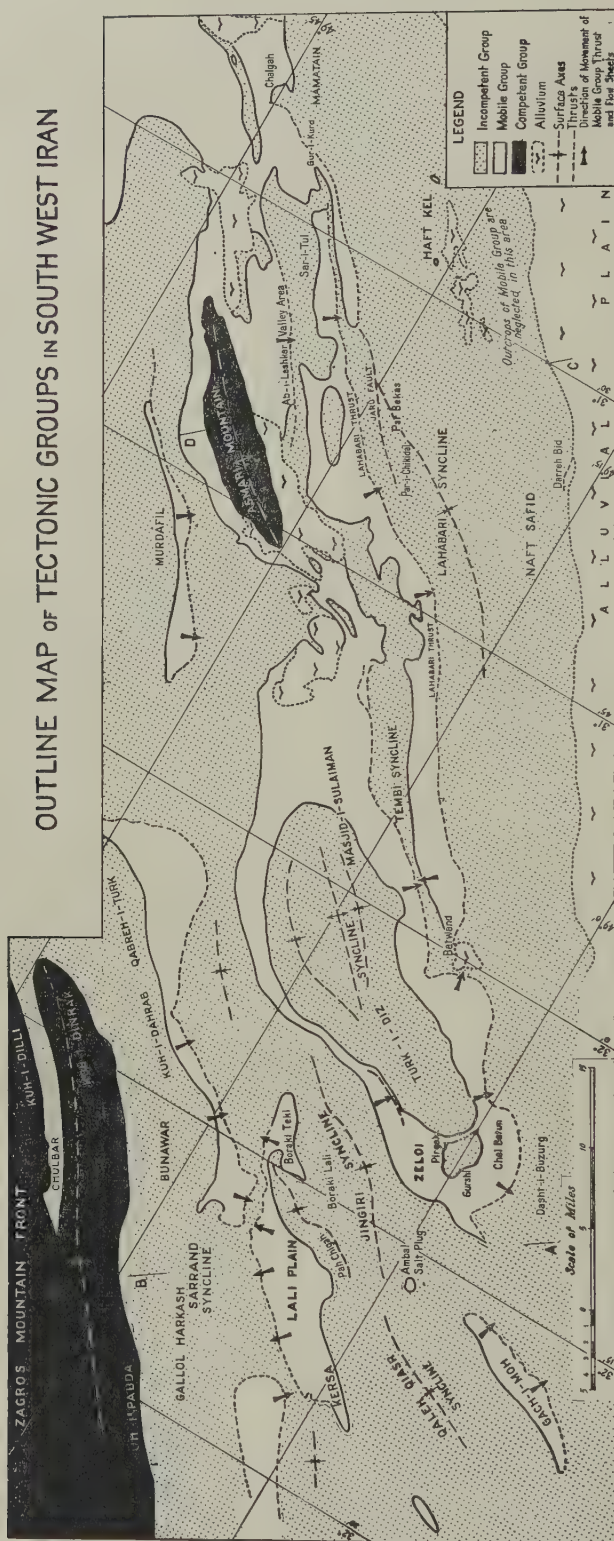
principles by which an approach may be made to the understanding of these tectonic problems, and discuss the history of one area in particular.

II. STRATIGRAPHY OF SOUTH-WEST IRAN

The normal stratigraphical divisions of an area are often inconvenient in discussions on tectonics; this is true of South-west Iran where the formations fall naturally into five tectonic groups. These, with their stratigraphical correlation, are as follows:—

TECTONIC GROUPS	STRATIGRAPHICAL DIVISIONS	
	Upper Bakhtiari	Pliocene
	Lower Bakhtiari	
5. Incompetent Group	Upper Fars	Upper Miocene
	Middle Fars	
	Lower Fars, Stage III	Middle Miocene
	Lower Fars, Stage II	
4. Upper Mobile Group	Lower Fars, Stage I	
3. Competent Group	Asmari Limestone and older beds	Middle Miocene to Upper Cambrian
2. Lower Mobile Group	Cambrian Salt	
1. Basement Group	Pre-Cambrian	

Of these, only Groups 3, 4, and 5 will be described in detail.

(a) *Competent Group*.—The Competent Group ranges from the Upper Cambrian to the Middle Miocene, is of great strength, and comprises chiefly massive limestones, shales and marls, with subordinate cherts, sandstones, and conglomerates. It may be as much as 20,000 feet thick in places, and in folding is controlled by competent massive limestones of Middle and Lower Cretaceous, and Jurassic age. It forms the great mountains of the Zagros Ranges and includes the limestone anticlines from which oil is produced so prolifically.

(b) *Upper Mobile Group*.—The Upper Mobile Group, which for convenience will be referred to as the Mobile Group, since there is no danger of confusion in this paper, is a stratified, largely chemical formation of massive anhydrite, salt, red and grey marls, and occasional thin limestones. The group is considered mobile on account of its instability under differential pressures, and of the tendency for its more plastic members to flow during folding. Its degree of mobility varies considerably with the percentage of salt present, the magnitude of the forces involved, the presence of water, and, most important of all, with time.

(c) *Incompetent Group*.—Superficially, it would appear that our Incompetent Group is wrongly named, since the group reacts to simple folding in a competent manner, displaying large, unfaulted, anticlines and synclines. This, we hope to show later is " pseudo-competency," being unrelated to any structural characteristic of the group.

The group comprises marls, thick silty sandstones, thin hard calcareous sandstones, thin limestones, anhydrites at the base and conglomerates at the top. Of these, the marls are greatly in excess of the other sediments, average figures being:—

Marl	—	74 per cent.
Sandstone	—	15 per cent.
Limestone	—	4 per cent.
Anhydrite	—	7 per cent.

The total thickness of the group varies considerably, but in its maximum development it reaches a deposited figure of over 12,000 feet in a number of areas, exclusive of the local deposits of massive Upper Bakhtiari conglomerates at the top.

III. CYCLE OF OROGENY

The cycle of orogeny, which culminated in the formation of the Zagros Mountain Ranges, began with the development of a major geosyncline in Permo-Carboniferous times, followed by heavy sedimentation throughout the Mesozoic Era. The first period of compression occurred during the Upper

SECTIONS TO ILLUSTRATE
DISHARMONIC FOLDING
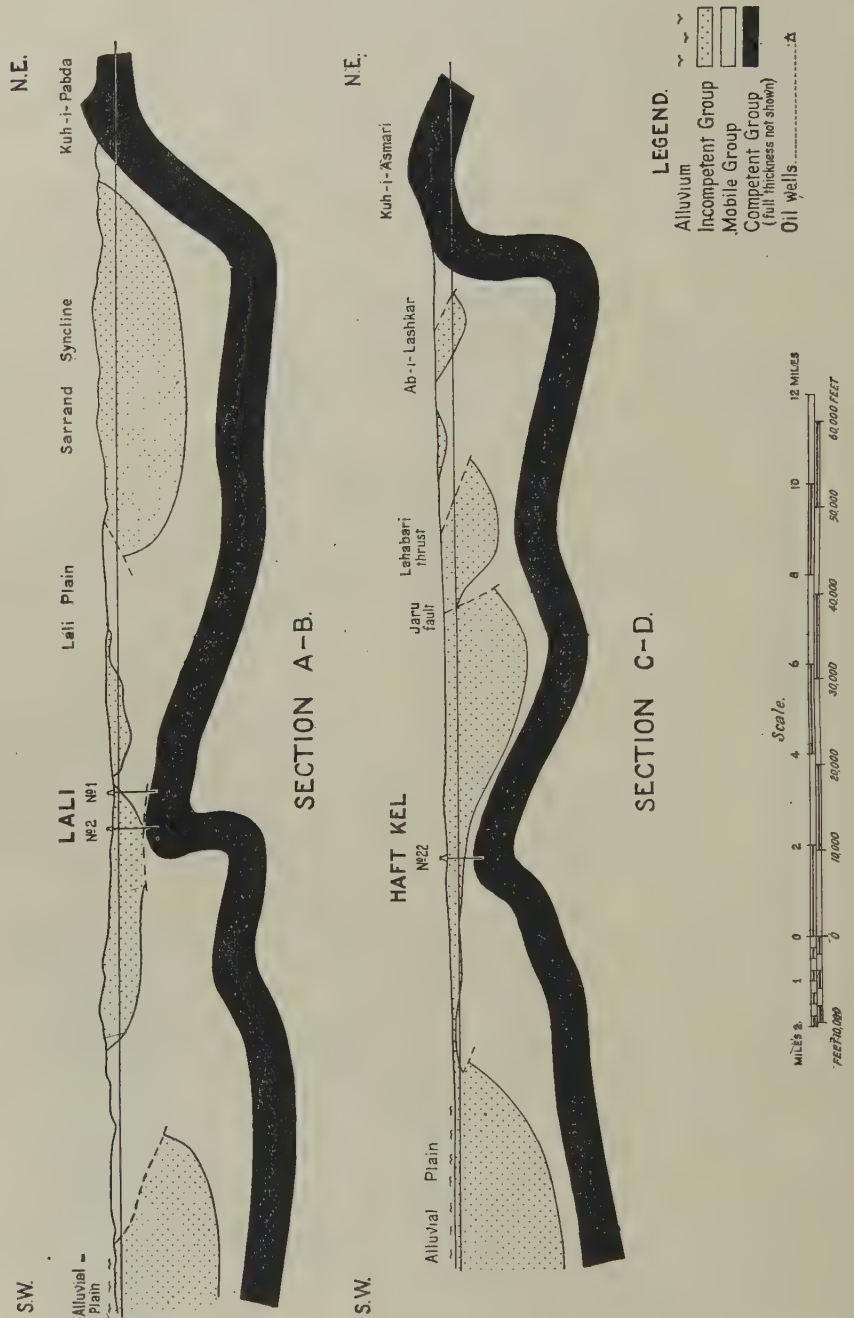IN THE OILFIELD BELT OF SOUTH WEST IRAN.

FIG. 2.

Cretaceous, and resulted in the emergence of hills of Senonian Marls to the north-east of Bakhtiaristan. Folding occurred again during and at the close of the Eocene, but appears to have been local in character.

The second, and major, period of compression began during the deposition of the Upper Fars, at the close of the Miocene, and continued with increasing violence until comparatively recent times. Its effects were graded from south-west to north-east. from gentle swellings under the Coastal Plain, through moderate folding in the oilfield belt and intense folding and imbrication in Bakhtiaristan and Kuhgalu, to the vast dislocations of the Iranian Nappes.

The cycle was closed by a period of regional uplift which is probably still in progress.

IV. FACTORS CONTROLLING THE DEFORMATION OF THE INCOMPETENT GROUPS

The deformation of the Incompetent and Mobile Groups has resulted from the transmission of a deep tangential orogenic force, by friction, through the overlying formations. Although outside the scope of this paper, for the sake of a proper understanding of the forces involved, we would record our conviction that the Pre-Cambrian basement of the Arabian Foreland, moving north-eastwards towards a crustal root under the Central Iranian Plateau, exerted a frictional " drag " force on the lower layers of the Competent Group in the same direction as its movement. This force was moderated by the lubricating action of the Cambrian Salt, but was sufficient, through the weight of overburden, to cause movement in the Competent Group towards the north-east. Such movement was resisted in the Median Zone, either by the movement in the opposite direction, of sediments in North-east Iran, motivated by the opposing limb of the orogen, or else by a relatively immovable mass. The result of this movement was to raise the Competent Group in a series of folds, growing more complex from the south-west towards the north-east. These folds, moving towards the north-east, transmitted the initial orogenic force to the Incompetent Group, partly directly, and partly indirectly through the plastic medium of the Mobile Group.

From our studies we have reached the conclusion that, apart from the fundamental movement towards the north-east of the Competent Group during folding, resulting in over-thrusting relatively to the south-west, four other major factors control the deformation of the overlying groups and cause the remarkable disharmonies with which we are concerned, namely:—

(a) *The Fluidity of Salt under Pressure.*—It is generally recognized that salt under pressure behaves as a plastic mass. Laboratory experiments and observations in salt mines show agreement in that salt bodies tend to flow under differential pressures of the order of 1 ton to the square inch. Laboratory experiments, however, are measured in minutes or hours, and mine observations, at the most, in tens of years, and what may be achieved by a given force even over the span of a man's life-time, can have no comparison with what may be achieved by the same force in a million years. The trend of modern thought is to consider the behaviour of rocks on a large scale, and over a period of millions of years, as resembling that of the viscous liquids and weaker plastics of our experience, rather than that of the hand specimens with which we are familiar. Certainly the evidence from salt plugs, and the convolutions of the salt groups of the Lower Fars, leave little doubt that in considering salt flow, under pressure, over long periods of geological time, we should apply the hydrostatic laws of fluids.

(b) *Depositional Variation of Salt.*—Since the degree of mobility of the Mobile Group is largely dependent on the percentage of salt present, the depositional variations in thickness of the salt are of great importance. Unfortunately, our knowledge of these is small, and is based on known thicknesses of the whole Group and the fact that salt is negligible or absent along parts of the mountain front. However, by reconstruction of salt movement from a large number of sections across the country we have built up the picture shown in Fig. 3, for variations in the Mobile Group, and believe that salt variations followed a similar relative pattern.

D
49

POSSIBLE ORIGINAL DEPOSITIONAL ISOPACHS ON THE MOBILE GROUP
DERIVED FROM MEASURED SECTIONS.

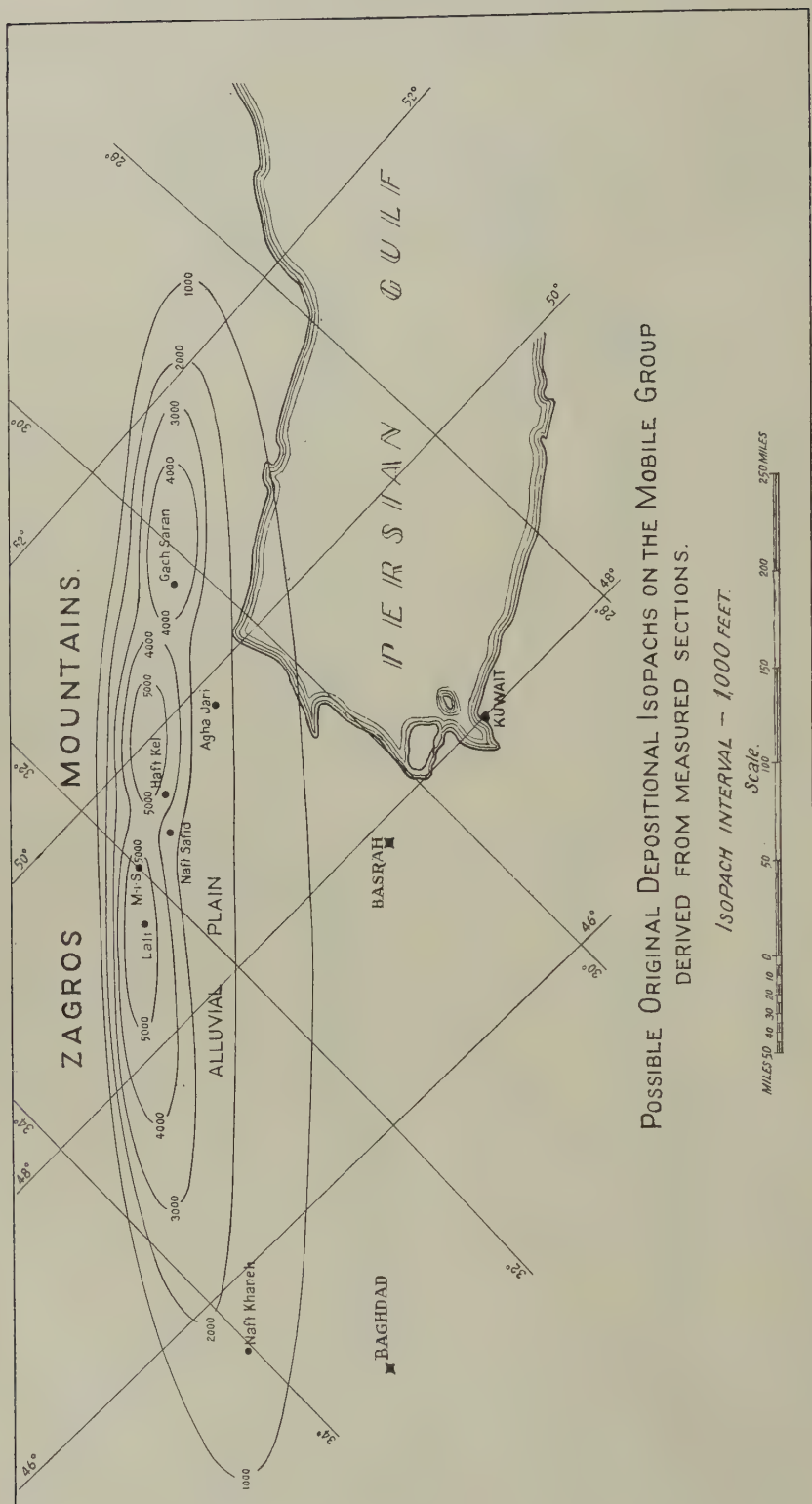ISOPACH INTERVAL ~ 1,000 FEET.

Scale.

FIG. 3.

(c) *Salt Movement under Differential Pressures.*—Applying the laws of fluids to salt movement, we can assume that under the differential pressures set up during folding, salt will flow from areas of high pressure to those of low pressure; the first problem in Iran being that of determining which areas produced high pressures. A study of thickness variations suggests that the most important of such areas were those overlying the crests of rising Asmari Limestone anticlines. The facts leading to such a supposition are as follows:—

(i) In all drilled areas, except two, the thickness of the Mobile Group shows a marked thinning over the anticlinal crest of the underlying Asmari Limestone domes. Typical examples are:—

LALI	South-west flank	Well 6................................	6938 feet+
		Well 3................................	1462 feet
	Crestal area	Well 2................................	274 feet
	North-east flank	Well 1................................	4107 feet
		Well 9................................	3778 feet
NAFT SAFID	South-west flank	Well 8................................	2878 feet
		Well 6................................	2263 feet
	Crestal area	Well 3................................	421 feet
		Well 4................................	321 feet
	North-east flank	Well 11	1182 feet
AGHA JARI	South-west flank	Well 6................................	3635 feet
		Well 10	2401 feet
	Crestal area	Well 2................................	512 feet
	North-east flank	Well 4................................	473 feet
		Well 3................................	646 feet
		Well 7................................	944 feet
GACH SARAN	South-west flank	Well 1................................	3467 feet+
		Well 2................................	4137 feet+
		Well 3................................	2388 feet
	Crestal area	Well 4................................	1139 feet
	North-east flank	Well 6................................	1558 feet
		Well 7................................	2146 feet

The two exceptions mentioned are (a) Masjid-i-Sulaiman, where the Mobile Group is entirely absent from the axial area of a subsidiary dome on the north-west pitching end of the structure but comes in, thinly, over the crest maximum, and increases rapidly down both flanks, and down the south-east pitching end, and (b) Haft Kel, where the group is again negligible on the axial area of a subsidiary dome on the north-west pitching end of the structure, and along a zone over the north-east flank, and increases rapidly over the crest maximum and down the south-west flank and the south-east pitching end. These anomalies have yet to be satisfactorily explained.

(ii) No decisive evidence of overstep, or unconformable junction within or at the base of the Mobile Group has been detected, either in the field or from the wells. This is not taken to prove that thickness variations from original depositional causes are not present, but that those due to tectonic causes are the more important.

(iii) Faulting and thrusting, with resultant repetition and cut-out of beds, within the Mobile Group, are common features of drilled columns over Asmari Limestone anticlines, particularly in the Gach Saran area.

(iv) The rapidity of thickness changes in salt bodies from adjacent wells over Asmari Limestone anticlines is more in keeping with tectonic variation than depositional variation.

One result of postulating high pressure over rising Competent Group anticlines, is that it demands that the Incompetent Group should have resisted uplift by the Competent Group, with a force considerably in excess of its own mass. This could only have happened, we suggest, if the uplift was localized, and by the regionally adjacent strata having exerted a drag on the point of uplift. It is

analogous to say that the centre square inch of a floor carpet would resist being pushed up from underneath by a man's thumb with a force far in excess of the mass of one square inch, and that a pat of butter, between the thumb and the carpet, would be squeezed out by virtue of the resistance to movement in the remainder of the carpet.

This also entails that the Incompetent Group, regionally, must have acted as a dead load on the Mobile Group, and that the tangential force, initiating folding in the Competent Group, was ineffective in the more central portion of the Incompetent Group sheet. Since salt was not deposited between the Competent and Incompetent Groups, either on the south-west side of the Persian Gulf, or on the north-east side of the Zagros Mountains, the two groups were in frictional contact at these two extreme edges of the basin, and presumably moved as one body. Consequently, as we have postulated placidity for the central portion of the Incompetent Group sheet, the shortening in the Competent Group, in the early stages of folding, can only have been taken up in the Incompetent Group, at the edges of the sheet. Since the rise of a single Competent Group anticline of 5,000 feet amplitude only results in a
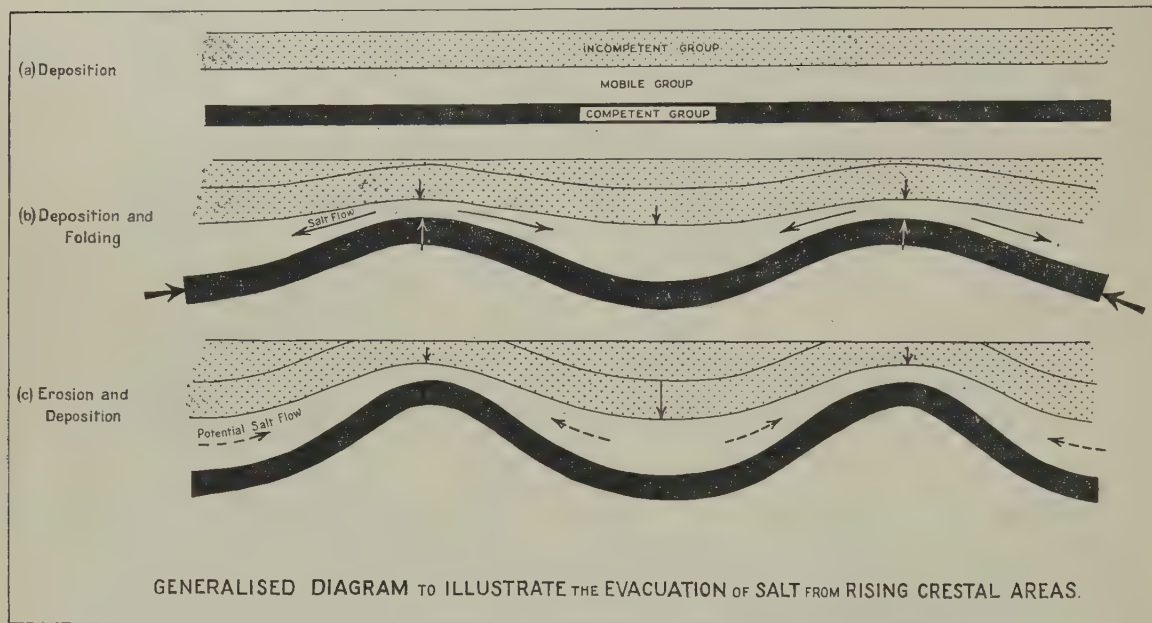

GENERALISED DIAGRAM TO ILLUSTRATE THE EVACUATION OF SALT FROM RISING CRESTAL AREAS.

FIG. 4.—*Approximate scale : 1 inch = 20,000 ft.*

shortening of a half mile in a sheet of 200 miles extent, this could easily have been accommodated by inter-group gliding, minor thrusting, and buckling wholly on the mountain edge of the sheet. Later, erosion would have removed all traces of this shortening.

In synclines, adjoining Competent Group anticlines, the only important pressure exerted on the Mobile Group, in the early stage of folding, was that effected by the mass of the Incompetent Group overburden, which at this stage was similar over both anticline and syncline. Consequently, the rise of a Competent Group anticline resulted in an area of high pressure over its crest, and an area of lower pressure in the adjoining synclines, so that salt was forced to evacuate the crestal areas of rising anticlines, and to flow down dip and down pitch into the surrounding synclinal areas.

Ideally this process, as shown in Fig. 4, if uninterrupted by additional forces in the Incompetent Group, should have been continuous until the closing stages of the folding, when the resisting force died out, leaving pressures due to the masses of overburden in control of the field. The tendency would then have been for salt to be forced back from synclinal areas to anticlinal areas, although this could

52

rarely have been attained owing to the small differential pressures available, and the frictional diffi-culties to be overcome. However, we believe that during the later stages of folding the Incompetent Group sheet no longer had freedom of gliding movement over the Competent Group on the mountain fringe, but was firmly held in closed synclines, and consequently tangential forces were then transmitted through the sheet, resulting in independent folding. The effect of this folding on salt flow cannot be generalized, and must be treated, individually, in each area.

(*d*) *Passive Role of the Incompetent Group.*—The inability of the Incompetent Group to transmit, directly, any high proportion of the tangential force has already been mentioned. This provides us with an immediate paradox between theory and practice. Owing to the flexibility and lack of coherent strength of the great majority of its constituents, a group containing 85 per cent of marls and soft sand-stones (since over 10 per cent of the sandstones are soft-weathering silty beds) cannot be capable of lifting its own weight during folding. It should require undersupport before it can be broadly anti-clinally folded, and it should act as a dead load, regionally, on any folded competent series underneath. If it were subjected to only a small fraction of the horizontal forces involved, it should invariably be thrust and faulted to a high degree. Yet this group, as mapped in the field and as tested by the drill, shows all the signs of competent behaviour. It forms broad, simple anticlines and synclines, often with steep or even vertical and overturned flanks, is only occasionally faulted, and very rarely shows any signs of internal shearing. It is significant, however, that the north-easterly edge of the Incom-petent Group sheet, immediately overlying the Competent Group without intervening salt, has prac-tically wholly been removed by erosion, and the few remaining pockets are in closed synclines between Competent Group mountains. Thrusting and buckling may well have been rife there.

It appears likely that in the more central portions of the sheet, where salt was present in great quantities, support was given to the Incompetent Group during folding by the Mobile Group, which partly moulded the group to its present shape and partly adapted itself to every change of shape of the latter when tangential forces were active within it. The Incompetent Group, therefore, reacted incom-petently to tangential forces, but by virtue of the properties of the plastic group, normally assumed a " pseudo-competent " form.

The initial adoption of these five principles provides an approach road, as it were, to the tangled jungle of Fars tectonics. How far they can be followed remains to be seen, but the all important fact is that they enable a logical start to be made on a complex problem.

In the second part of the paper we shall apply these principles to the study of an area in which the tectonic problems are unique, and attempt to unravel the sequence of past tectonic events.

V. TECTONIC ANALYSIS. THE LALI AREA

The Lali Area, which is illustrated by the map in Fig. 1 and the section in Fig. 2, comprises from south-west to north-east, a fore-syncline buried under the alluvial plain and overthrust by the Chal Batun Mobile Group, the Gurshi-Pirgah Syncline, the Zeloi Mobile Group, the Qaleh Qiasr and Jingiri Synclines, the Kersa-Boraki Teki anticlinal area of Mobile Group, and the Gallol Harkash-Sarrand-Bunawar Synclines. The synclines are all Incompetent Group.

The Qaleh Qiasr and Jingiri Synclines have been shown by a Seismic Refraction Survey and by the drill to rest directly on the Lali Asmari Limestone Anticline. The latter syncline overlies the crest maximum and the south-east pitching end of the anticline, and the former overlies the north-west pitching end. In this combination of structures lies the key, we believe, to the tectonic problems of the area.

The anomalous position of an Incompetent Group syncline immediately over a Competent Group anticline, may result from any one, or any combination, of the following circumstances:—

1. The movement of the Incompetent Group horizontally over the underlying Competent Group.
2. The movement of the Competent Group horizontally under the overlying Incompetent Group.

3. The formation of the Competent Group anticline in place under the overlying Incompetent Group syncline.

4. The formation of the Incompetent Group syncline in place over the Competent Group anticline. Some of these possibilities, if examined in detail, are capable of elimination.

1. *Movement of Incompetent Group over the Competent Group.*—A consideration of the Lali area at the north-west end of Fig. 1 brings out two important points:—

(a) That the Incompetent Group may be taken, for all practical purposes, as a continuous sheet from the Alluvial Plain to the Mountain Front, broken occasionally by flows and inliers of Mobile Group. If then, any considerable horizontal movement has occurred in the Incompetent Group cover, then that cover has moved as a single unit of at least 1,500 square miles.

(b) With the exception of flow south-westwards from under the Sarrand-Bunawar Syncline, the major Mobile Group flows are radial about the Lali Asmari Dome. This suggests that the break through of the mobile Lower Fars, Stage I, was a regional affair, directly connected with the rising of the Asmari Dome.

Measurements on three sections across the area give the following minimum distances by which the Qaleh Qiasr and Jingiri Synclines would have moved relatively south-westwards, if they had once been folded in Asmari synclines and then thrust into their present positions:—

> Section I — 30,000 feet (not illustrated)
> Section II — 50,000 feet (fig. 2)
> Section III — 40,000 feet (not illustrated)

However, since such movements could not be taken up by individual synclines, we must consider whether they could have been taken up regionally by the whole Incompetent Group cover, that is whether 1,500 square miles of Fars country could have been thrust forward eight miles, relative to the underlying Asmari Limestone.

There are several reasons why such an idea is untenable, but at least one is conclusive. As shown in Fig. 1, the Incompetent Group has been mapped almost continuously along the Mountain Front, past Kuh-i-Dahrab and Qabreh-i-Turk, around the pitching end of Kuh-i-Dinrak, until it is safely anchored in the narrow syncline of Chulbar in front of Kuh-i-Dilli. No movement of the group in this syncline has been possible.

2. *Movement of Competent Group under the Incompetent Group.*—If the Lali Asmari Anticline had moved south-westwards a distance of eight miles relative to the Incompetent Group cover, it must have done so independently of Kuh-i-Pabda and the Mountain Front, otherwise the objection lodged in the previous section would also hold here. To have moved independently is to invite consideration of an eight-mile wide rift in the Competent Group, or alternatively an original amplitude of 30,000 feet. Either, or a combination of the two on a lesser scale, can be completely ruled out.

3. *Formation of the Competent Group Anticline in place under the Incompetent Group Syncline.*— If this possibility is to differ from the mechanics of previous sections, we must consider an Incompetent syncline shaped by an underlying Competent syncline, and later being raised by an anticline rising from the original Competent syncline. This can be visualized by a wave front passing through the folded Competent sheet and completely, or partially, changing the phase of the existing folds, or by the compression of the syncline between two approaching Competent anticlines. The distribution of Competent folds and the relative simplicity of the existing Incompetent synclines preclude these possibilities in the Lali area.

4. *Formation of the Incompetent Group Syncline in place over the Competent Group Anticline.*— The previous three possibilities being untenable, we may expect the answer to the problem to lie in the fourth. And so, we believe, it does.

In Fig. 4 we illustrated an idealized series of events which might occur when salt was squeezed out from the crestal areas of rising Competent Group anticlines. It is immediately obvious that the sections at Lali differ from the result obtained in Fig. 4 (c), but we hope to show that this difference is only due to a greater volume of Mobile Group contained in the Competent Group synclines.

Two factors were outstandingly important in the tectonic history of Lali:—

(a) The Mobile Group contained an unusually high percentage of salt, rendering it extremely mobile, and the original deposited thickness of the group may have been as much as 6,000 feet;

(b) As previously stated, the Incompetent Group was securely held in a closed syncline behind the first range of Competent Group mountains to the north-east.

These two factors, together with the present form of the Lali sections, lead us to conclude, first, that during the early stages of folding the flow of salt from the crest of the Lali anticline, and from the next anticline to the north-east was, potentially, so extensive that the syncline developing between the two anticlines was never large enough to contain it. Consequently, the Incompetent Group over the contained syncline never assumed the synclinal form shown in Fig. 4. As folding continued, four sets of forces developed:—

(i) Considerable frictional drag on the base of the Incompetent Group, inwards from each crest towards the centre of the contained syncline, was caused by the squeezing out of masses of Mobile Group. This tended, potentially, to raise the Incompetent Group into a flat anticline over the Competent Group syncline.
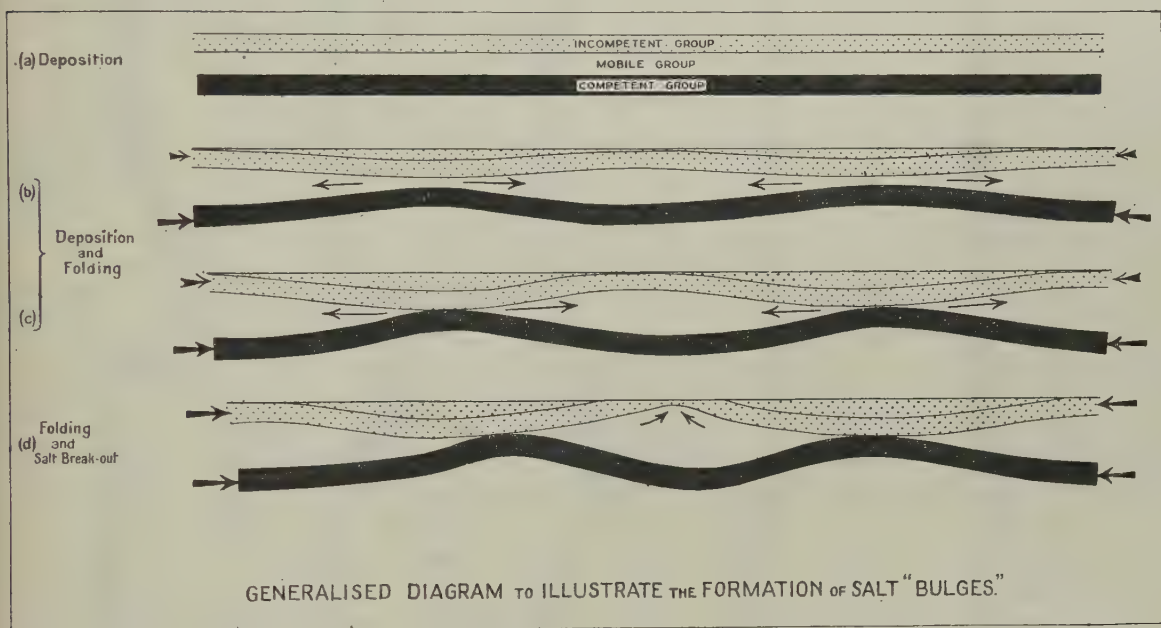

GENERALISED DIAGRAM TO ILLUSTRATE THE FORMATION OF SALT "BULGES."

FIG. 5.—*Approximate scale : 1 inch = 40,000 ft.*

(ii) The closing in of one Competent Group anticline on the next one to the north-east, due to shortening in the folded group, added to the frictional effects of (i).

(iii) The squeezing of salt, in a narrowing Competent Group syncline, developed a vertical component in the internal forces in the salt, which again tended to raise the Incompetent Group anticlinally over the Competent Group syncline.

(iv) With the growth of closing anticlines and synclines further to the north-east, compressional forces became active within the Incompetent Group, over the Lali area.

Since the Incompetent Group was incapable of raising its own weight it could only bend, as distinct from buckle, where it received uplift from the Mobile Group, and this uplift was greatest over the salt accumulation in the Competent Group syncline. The net result of these forces was to raise the Incompetent Group into a flat anticline over the Competent Group syncline, whereupon, since the deposition

SECTIONS TO ILLUSTRATE THE POSSIBLE TECTONIC HISTORY OF THE LALI AREA.

(a) Upper Fars.

(b) Late Upper Fars.

(c) Early Middle Bakhtiari.

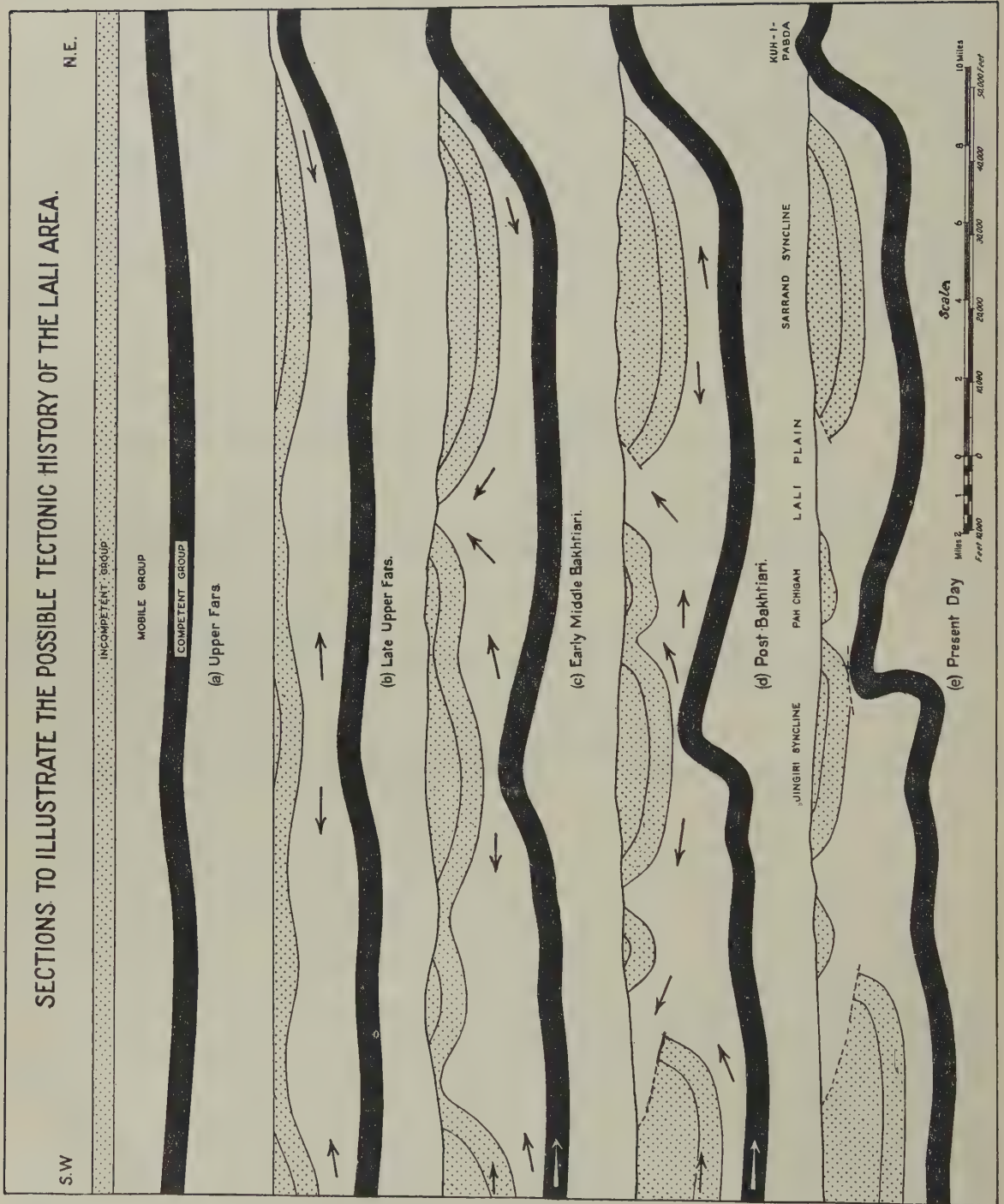(d) Post-Bakhtiari.

(e) Present Day

FIG. 6.

of the Upper Fars-Bakhtiari beds was continuing, sedimentation increased over the Competent Group anticlines and decreased, correspondingly, over the synclines. This idealized sequence of events is illustrated in Fig. 5.

Once the initial stages of the folding were completed, and the more mobile elements had been squeezed out from under the extensive fore-syncline to the south-west of the area, a measure of frictional contact was established between the upper and lower groups in this syncline, resulting, with the movement of the Competent Group north-eastwards, in the Incompetent Group being drawn in the same direction, and so increasing the compressional forces in that group over the whole area.

Briefly then, we consider the later tectonic history of the Lali area to have been in four phases. The first phase opened in early Pliocene times after some 4,000 feet of Incompetent Group had been deposited in a secondary geosyncline lying in front of a rising mountain belt. The folding of this geosyncline resulted in the formation of two parallel anticlinal Competent Group structures; to the north-east of the area was the mass, later to be known as Kuh-i-Pabda, and in the centre of the area the Lali Dome. Salt and masses of Mobile Group were rapidly squeezed out from the crestal areas, resulting in the formation of salt bulges on either side of the latter. The syncline on the south-west side of Lali was also fed with salt from the north-west pitching end of the Masjid-i-Sulaiman dome, and from under the fore-syncline further to the south-west. This is illustrated in Fig. 6(b).

In the second phase the onset of compressional forces at the north-east and south-west edges of the area, with the aid of other forces previously mentioned, facilitated the formation of two anticlinal arches in the Incompetent Group over the flattish Competent Group syncline south-west of the rising Lali Dome, and of a single broad Incompetent Group arch to the north-east of the dome. The growth of the latter arch was facilitated by compression from the gravitational effects consequent upon the rise of " Kuh-i-Pabda " above the area to the south-west of it. Later, in Lower Bakhtiari times, the accumulation of detrital material in the Incompetent Group synclines and the erosion of the anticlines, resulted in more salt being squeezed into the Competent Group synclinal areas, and the accumulative growth of the bulges. The close of Lower Bakhtiari deposition saw the end of the second phase when, with the denudation of the Fars hills over Kersa, Zeloi, and the Lali Plain largely completed, the Mobile Group was exposed over extensive stretches. Squeezing of the Mobile Group, out over the adjacent surface synclines, may already have begun.

The third phase opened with the deposition of the Middle Bakhtiari Conglomerates in basins in the denuded land surfaces of the Qaleh Qiasr and Gallol Harkash-Bunawar Synclines. There is no evidence of these conglomerates, or later ones, having been deposited in the Jingiri Syncline, possibly because continual rejuvenation, due to the rising Asmari anticline underneath, kept the topography in an elevated state until comparatively recent times. How much the added weight of these conglomerates, and the later Upper Bakhtiari Conglomerates, contributed to the formation of the salt bulges is not known; some effect they undoubtedly had. As a point of interest, we may mention that the deposition of these conglomerates, although thousands of feet thick in places, had no stiffening effect upon the Incompetent Group, but actually weakened it, since they were laid down in largely unconnected basins.

At the close of the period of Upper Bakhtiari deposition, the final phase began. Widespread orogenic movements recurred over the whole of South-west Iran, and the subsequent strong over-thrusting of Lower Fars, Stage I, over the Upper Bakhtiari Conglomerates on the south-west side of the Gallol Harkash-Bunawar Syncline, and of the Chal Batun and Gach Khalaj sheets over the Dasht-i-Buzurg fore-syncline, argue violent squeezing of the Mobile Group in the respective bulges. At this period of the orogeny, we visualize the south-west fore-syncline to have been in greater frictional contact with the underlying Competent Group than at any previous stage. The effect of the increased folding in the Competent Group at this stage, therefore, was to squeeze out the last remaining fluid portions of the Mobile Group over its anticlinal crests, and by virtue of the frictional contact, to drag the fore-syncline north-eastwards under the apparently overthrust Lower Fars Sheets. This is illustrated in Fig. 6 (d) and (e). Similarly the closing up of the Lali Competent Group anticline to the north-east on the Kuh-i-Pabda fold, or any intervening fold, the existence of which we are unaware, caused such

squeezing of the bulges as resulted in the thrust sheets to the north-east of the Lali Plain, and the Lower Fars Stage I " plugs " between the Jingiri and Pah Chigah Synclines.

The last phase was completed in comparatively recent times by the relative uplift of the north-east side of the Jingiri Syncline compared with the south-west, which may have been due either to the last upward movements of the Lali Dome or to the draining away of salt under the south-west edge owing to the release of pressure resulting from the exposure of the Mobile Group at Zeloi.

VI. CONCLUSIONS

In conclusion, we feel that this description of the tectonic history of Lali is in the nature of being " wise after the event "—the event being the discovery of the Lali Asmari Limestone dome. But we feel, too, that successful interpretation of deep Competent Group structure, which is the objective of geological mapping in South-west Iran, should become increasingly frequent with the development of our knowledge of the laws of movement within the Mobile and Incompetent Groups.

As a start only, in the development of this knowledge, we have proposed five basic principles, any of which may require modification as further study is made of the subject. Our immediate hope, however, is that they may prove of some value as lines of approach to a highly complicated problem.

VII. ACKNOWLEDGMENTS

REFERENCES

BUSK, H. G., and WEATHERHEAD, W. R. A. 1918. *One inch to one mile geological map of Abid-Lali-Haft Shaidan.* Unpublished.

LEES, G. M. 1931. Salt—Some Depositional and Deformational Problems. *Symposium on Salt Domes. Journ. Inst. Petr. Techn.*, May and June 1931.

OWEN, L. 1931. Salt Dome Theory. *Symposium on Salt Domes. Journ. Inst. Petr. Techn.*, May and June 1931.

STÖCKE, K. 1936. Fleissgrenzen von Salzgesteinen und Salztektonik. *Kali, verwandte Salze und Erdöl.* XXX Jahrgang.

PETROLEUM GEOLOGY IN PAKISTAN*

By E. R. GEE

Great Britain

ABSTRACT

The paper deals principally with Western Pakistan (including Baluchistan and Kalat, N.-W.F. Province, West Punjab and Sind) with which territory the author is familiar.

It summarizes the geological history and stratigraphy of these areas and describes in greater detail the Tertiary and Mesozoic sequence.

Regarding the geological structure of the region, the author refers very briefly to the tectonic belts that lie immediately outside the areas within which the occurrence of possible resources of petroleum is recognized. These outer zones include in the west the sedimentary-igneous belt of the Chagai district of western Baluchistan and the outer thrust zone of the lower Himalayas of southern Kashmir, etc.

He treats the region which appears to offer possibilities from the point of view of petroleum exploitation under three sub-heads:
1. The Baluchistan–Mekran area.
2. The folded and folded-faulted uplands of the Sulaiman—Salt Range tectonic belt.
3. The alluvial plains of the Indus-Jhelum valley.

The paper includes a brief history of petroleum exploration and exploitation in N.W. India to date; tentative views are expressed regarding future possibilities. A brief reference is made to the age of the Saline series in the Salt Range.

INTRODUCTION, LITERATURE, ETC.

PAKISTAN, now including Kalat and adjoining smaller States, was constituted on the 15th August, 1947. The greater part of the dominion, with its capital Karachi, lies in the north-west. This area, known as West Pakistan, includes what was formerly British Baluchistan, the North-West Frontier Province, Sind, and the western part of the Punjab. In north-eastern India, the eastern part of the old province of Bengal now forms East Pakistan, having Dacca as its capital and Chittagong as its main port. This paper deals mainly with West Pakistan.

The frontier separating West Pakistan and the dominion of India coincides approximately, over the greater part of its length, with a broad palaeogeographical boundary. Though this frontier tract is now covered very largely by the thick alluvial deposits of the Indus river system, there is good reason to believe that during prolonged periods of the late Palaeozoic, Mesozoic, and early Tertiary eras the present political boundary corresponded roughly with a part of the shore-line separating the Gondwana continent (of India) to the south-east from the marine Tethys of the north-west, the coast fluctuating periodically from one side to the other of what is the present frontier.

In the case of East Pakistan the same correspondence politically and geologically is not maintained. The frontier with West Bengal and Assam again largely traverses alluvium, this time of the Ganges, Brahmaputra, and Meghna river systems, beneath which at an unknown but probably very great depth, Tertiary and Gondwana rocks are likely to occur. Further east towards the frontier with Burma, in Sylhet and the Chittagong Hill Tracts, the boundary between East Bengal and India cuts across the north-south trending higher Tertiary sediments, which are here common to both dominions.

In so far as petroleum is concerned, with the exception of the Digboi and associated Tertiary areas of north-eastern Assam and certain Tertiary tracts in southern Assam near the present East Pakistan frontier, almost all the regions of the Indian sub-continent that, on available evidence, appear to offer prospects of the occurrence of oil lie in Pakistan. It should, however, be emphasized that, up to date,

---

* For joint discussion of this and other papers see pp. 68-73.

actual oil prospecting in these Pakistan areas has proved disappointing, very appreciably greater production having been obtained from the Digboi field in Assam (India).

Rather more than a quarter of a century ago, the proved and possible oil-bearing areas of North-west India and Assam were described by Sir Edwin Pascoe of the Geological Survey of India. His two memoirs contain bibliographies of earlier published reports among which those of A. B. Wynne and E. Vredenburg in the case of the Punjab and Kohat (N.-W.F.P.), and of Baluchistan, respectively, deserve special mention as notable pioneer surveys.

For some years prior to Pascoe's survey, geologists of several oil companies, principally the Attock Oil Co. and the Burmah Oil Co., had carried out more detailed geological work over particular areas and reconnaissances over wider tracts of country, and their work has been intensified during the past three decades. Later, the Whitehall Petroleum Corporation carried out extensive field work.

GEOLOGICAL MAP OF WEST PAKISTAN

(Compiled from Maps published by the Geol. Surv. of India.)

Scale

100   50   0   100   200   300 Miles.

Pleistocene and Recent............ Siwalik system............
Oligocene and Lower Miocene...
Eocene.............................. Mesozoic..............
Deccan Trap and ultra-basic intrusives............
Carboniferous and Permian........................
Older Palaeozoic and Pre-Cambrian........................
        Archaean......

Nasratabad

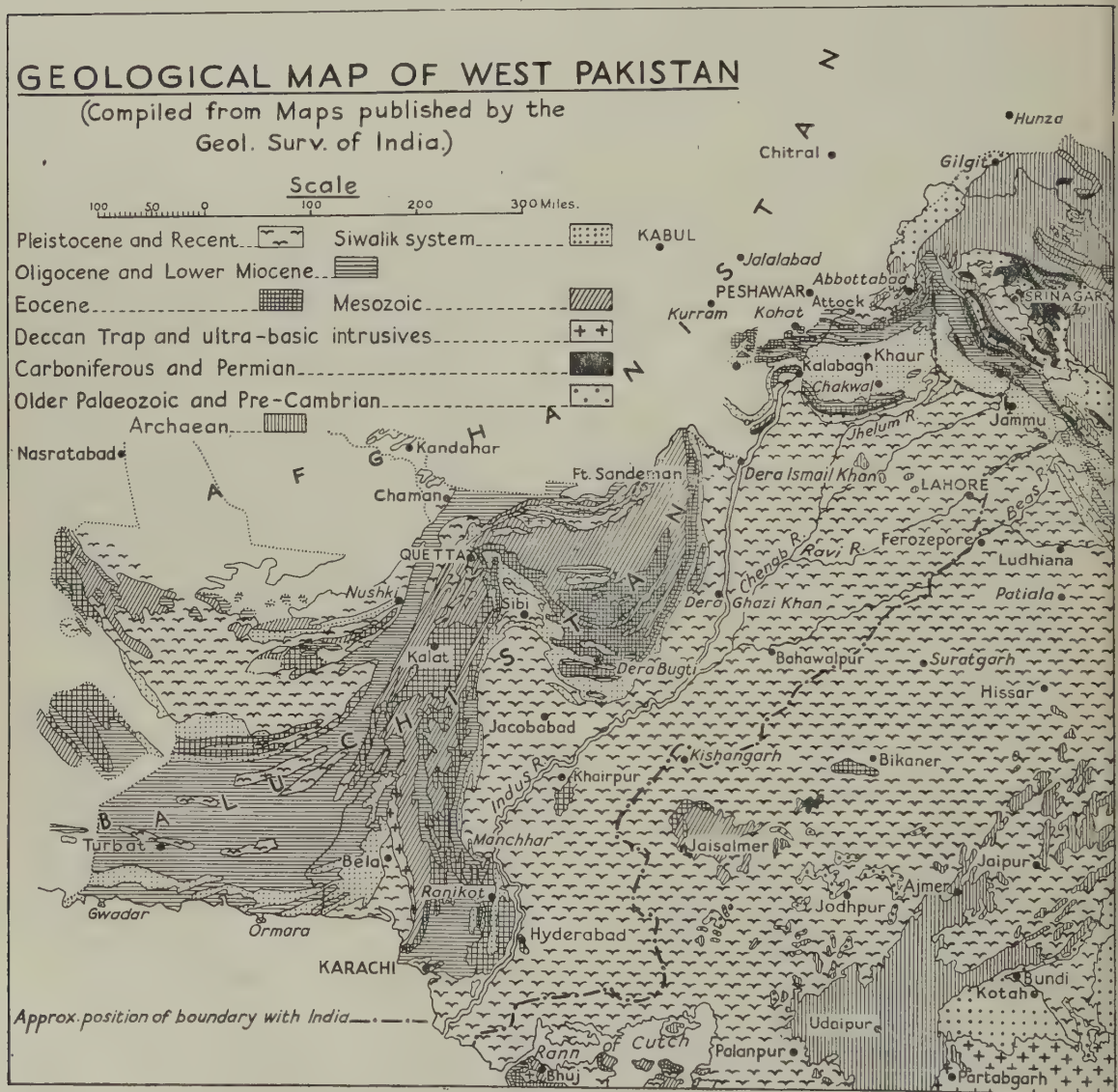Approx.position of boundary with India

FIG. 1.

Fortunately, during recent years, the summarized results of much of this work have been published. In the case of the producing Punjab fields, the earlier surveys were carried out by Mr. E. S. Pinfold of the Attock Oil Co.

Apart from the work of commercial firms, the Geological Survey of India continued to show considerable interest in these regions, mapping wide areas in greater detail than had previously been done. In this connection the work of the palaeontologists, both in India and inth is country, deserves special mention. As a result, the past 25 years has shown an appreciable advance in our knowledge of the geology of large parts of West Pakistan. No recent official survey has, however, been made of the East Pakistan (East Bengal) area where the higher Tertiaries offer less interesting problems.

In East Pakistan we have the typical monsoon climate with a very high June-September rainfall. As a result, the Upper Tertiary hill tracts of the Chittagong district, beyond the alluvial plains of the Brahmaputra and Meghna rivers, are covered by dense tropical jungle usually with a thick soil-cap, and rocks crop out only occasionally. In West Pakistan, however, conditions are quite different. There, a very limited rainfall with long periods of dry weather has resulted in a relatively sparse, and often extremely sparse, forest cover. Rock exposures in the hill tracts beyond the alluvium-covered plains are, therefore, on the whole good to excellent, affording clear sections of the stratigraphy and structure. These areas of West Pakistan and Kalat, which are of interest to the oil geologist, include the Himalayan foothills south of Kashmir; the Potwar plateau and Salt Range together with their continuation westwards across the Indus river in the North-West Frontier Province; the Sulaiman Range and its continuation southwards through eastern Baluchistan, Kalat, and Sind; and the Mekran region of south-western Kalat. In addition the plains of the Indus river system adjoining the above hill tracts are of interest in that suitable structures, possibly containing oil, may occur in the consolidated sedimentaries beneath the recent alluvial capping.

GEOLOGICAL HISTORY

Regarding Pakistan's geological history, shallow water, marine conditions prevailed over large parts of West Pakistan during much of geological time. Intervals of non-deposition, uplift and erosion were, however, also an important feature of the geological history of the region with, at times, estuarine, fluviatile, and lacustrine sedimentation, the latter being predominant during the Middle and Upper Tertiary. In general, the deeper waters of the Tethys lay to the north and west, thus giving the more complete sedimentary sequence of the western Himalayan region and of the Sulaiman belt. In the Salt Range–Indus valley region, that is to the south and east of this open sea, coastal deposition was more prevalent. The north-western edge of the Indian portion of Gondwanaland lay still further to the south-east, though at no great distance and, during periods of relative emergence, this continent extended northwards and westwards well into West Pakistan.

An important feature of the earth movements that affected the region is the absence, until the late Tertiary, of intense folding and faulting; whilst the paucity of igneous activity except in the northern and western parts of Baluchistan is significant. In most cases those pre-Himalayan earth movements that interrupted the cycle of marine sedimentation caused gentle, though often prolonged uplift, resulting in depositional unconformities insufficiently irregular to be recognized in single sections, and only discernible by mapping over wide areas or by detailed palaeontological study. This absence of catastrophic pre-Tertiary orogenic movements in the region is important from the point of view of the possibility of the occurrence of oil in the Cambrian strata.

Summarized, the sequence of events in West Pakistan, notable from the petroleum geology standpoint are:—

(i) Marine gulf and warm, arid, coastal conditions during much of the Cambrian and possibly late pre-Cambrian, in at least the Salt Range–Trans-Indus region. During that period thick deposits of rock salt, gypsum, and saline marl, with thin oil shales were laid down forming the Punjab Saline series. Arid and shallow water conditions followed giving rise to the Purple Sandstone–Neobolus

Shale–Magnesian Sandstone–Salt Pseudomorph sequence, the latter including thick gypsum-anhydrite deposits to the west of the Indus river. Certain portions of this sequence are tentatively correlated with a part of the Vindhyan succession of Rajputana. Whether this phase of deposition extended to the southern and south-western parts of West Pakistan is uncertain, the oldest rocks exposed in those regions being small inliers of Permian (Productus) Limestones in the Baluchistan uplands.

(ii) Higher Cambrian to Silurian beds are absent from West Pakistan south of the Himalaya, and it is probable that the southern shore line of the Tethys had retreated northwards during at least the greater part of those periods. Uplift and erosion undoubtedly occurred in the northern part of the Punjab during the latter part of that time; as a result, the succeeding Talchir Conglomerates of Upper Carboniferous age rest unconformably on the various members of the Cambrian overlapping in the western part of the Salt Range on to the Punjab Saline series.

(iii) Following a second period of widespread marine deposition during Upper Carboniferous, Permian, and Triassic times, shallow water, marine and estuarine conditions again set in over parts of the lower Indus region resulting in a very variable Jurassic sequence. Predominantly arenaceous sediments with impure carbonaceous horizons were laid down in the Salt Range and Trans-Indus areas. Similar fluctuating marine, estuarine, and fluviatile conditions probably existed further south in parts of Sind. To the north and west, in parts of the N.-W.F.P. and in Baluchistan marine sedimentation prevailed giving rise to a very thick sequence, predominantly calcareous. In the Salt Range region, periodic emergence during the Jurassic is marked by impure lateritic beds. During the succeeding Cretaceous, conditions were broadly comparable, with coastal arenaceous deposition in the northern Punjab during very limited periods and calcareous-argillaceous sedimentation in the more open sea of the Baluchistan region.

(iv) The latter part of the Cretaceous witnessed a recurrence of earth movement throughout at least the greater part of northern India. This phase of uplift and erosion was, like the mid-Palaeozoic phase, not accompanied by marked folding or acute disturbance. As in north-eastern India the resulting unconformity is often clearly marked by a bed of laterite. In the case of certain parts of the Baluchistan uplands, however, the break in sedimentation was of very limited duration and only by detailed palaeontological study is the junction of the Upper Cretaceous and Lower Eocene limestones discernible.

(v) Widespread subsidence again occurred in north-west India during the Lower Eocene, the Ranikot sea transgressing across the greater part of the region and resulting in the deposition of a predominantly calcareous-argillaceous, very fossiliferous series, characterized by numerous foraminifera. Carbonaceous shales and thin, locally workable, coal seams occur in places in the Ranikot, indicating lagoonal conditions. In the south, in Sind and Baluchistan, rather similar conditions continued into the Middle Eocene but with predominantly argillaceous-arenaceous sedimentation with several thin coal seams (Laki) in some areas, followed by limestones and shales with gypsum during the succeeding Khirthar. Further north, in the northern Punjab and the N.-W.F.P., conditions of sedimentation were more varied during Laki-Khirthar times. In the early Laki, foraminiferal limestones and shales were deposited. This phase was followed by uplift of varying degree which resulted in the cessation of deposition in many areas and the formation, during late Laki or early Khirthar times, of a marine gulf in the Kohat-Potwar area. Within this gulf the thick deposits of rock salt capped by gypsum, including some oil shales, were laid down. These constitute the Kohat Saline series. Brackish to freshwater conditions followed for a short period, subsequent to which, during later Khirthar times, a further marine incursion gave rise to the uppermost limestone-shale beds of the Eocene of those areas.

(vi) Upper Eocene times witnessed the earliest phase of Himalayan orogenesis, which phase continued during at least the early Oligocene. The northern part of West Pakistan was uplifted above sea level, whilst to the south-west the Sulaiman mountain belt of Baluchistan was initiated, resulting in the formation of the Indus gulf to the east and the Mekran sea to the west. From that time onwards, sedimentation in these two areas appears to have remained relatively distinct, though during at least

the later stages of the Tertiary, after the formation of the present Arabian sea, they were probably connected around and across what is now the southern end of the Sulaiman chain. Detailed geological field work is, however, necessary before the exact conditions can be ascertained. This early Tertiary phase of Himalayan-Sulaiman uplift was naturally accompanied by rapid erosion in certain areas, particularly well seen in the Salt Range–Trans-Indus region and in the Baluchistan uplands. These latter events have an important bearing on the petroleum geology of West Pakistan. In the Mekran gulf to the west and in the southern part of the Lower Indus gulf to the east of the uplifted Sulaiman belt marine deposition continued. In the Mekran sea, at least several thousand feet of predominantly argillaceous sediments, the Kojak Shales, were deposited. Thick silts, soft sandstones, and clays of higher Tertiary age succeed the latter in the southern Mekran. In the case of the Indus gulf, east of the Sulaiman belt of uplift, the sea rapidly retreated southwards, depositing Oligocene sediments, the Nari stage, in western Sind. The filling up of this low-lying, subsiding tract by many thousands of feet of fluviatile and lacustrine sandstones, clays and conglomerates—the well-known Murree, Siwalik, Gaj, and Manchhar sequence—followed during the Middle and Upper Tertiary. During the latter part of this period the intense earth movements that gave rise to the Himalayan, Hindu Kush, and Sulaiman mountain belts of recent times took place. With the erosion of these mountain arcs, the thick alluvial sediments now covering the plains of West Pakistan were laid down. These latter orogenic movements, which so largely govern the problems of petroleum geology in the region, are briefly described below.

STRUCTURAL CONSIDERATIONS

Although the importance of the mid-Palaeozoic, Jurassic, and late Cretaceous earth movements of the West Pakistan region must not be overlooked in any study of the petroleum geology of the area, the effects of the period of Himalayan orogenesis are obviously the most spectacular and of the greatest consequence. On the one hand we have their bearing on the present distribution of the Eocene —the likely source rocks of the oil so far obtained from the Pakistan fields. On the other hand, these earth movements were almost wholly responsible for the folding, faulting, and thrusting that governs the distribution of the oil, irrespective of its original source.

The Himalayan movements affecting the region were naturally more intense in the north and west. As far south as the Attock area of the north Punjab large-scale thrusts are an important feature of the tectonics. In the south-west in Baluchistan, just beyond the line of Quetta, large thrusts have undoubtedly affected the Eocene–Kojak Shale (Oligocene) sequence.

To the south and east of these thrust belts the Potwar, Salt Range, Kohat Salt region of the Punjab and the N.-W.F.P. and the limestone uplands of Baluchistan and Kalat are characterized by folding accompanied by faulting, but without immense thrusts. It is reasonable to conclude that these fold structures are repeated in some cases beneath the alluvial deposits of parts of the Indus valley region. These areas of fold structures that exist to the south and east of the thrust belts are naturally the ones of the greatest interest to the oil geologists, as are also similar structures in the southern part of the Mekran to the west of the Sulaiman uplands.

EVIDENCE OF PETROLEUM, PAST ACTIVITIES

In the folded areas of both the north and south-west parts of West Pakistan, oil seepages occur at a number of places. In the north, within the Potwar, Salt Range, and Kohat Salt Region, seepages are confined to the Eocene, Murree, and Siwalik beds or, when the Eocene is missing, the actual seepage may occur in the Mesozoic sandstones that immediately underlie the unconformity at the base of the Murree-Siwalik sequence.

In the case of the pre-Tertiary strata, thin lignitic beds yielding oil on distillation occur in the Jurassic of the Trans-Indus range. Also, a gas seepage occurs in Siwalik strata probably overlying Jurassic beds of the south-western end of that range in Bhittani tribal territory.

In the Salt Range the Punjab Saline series (Cambrian or pre-Cambrian) includes oil shales, mainly of low grade, both above and below the rock salt stage, and an appreciable show of inflammable gas was encountered in an exploratory drift in rock salt in the eastern part of the range.

Further south seepages occur in the Eocene and, at Sanni sulphur mine in Kalat State, heavy oil is met with in the Nari beds. Mud volcanoes with inflammable gas in the higher Tertiaries of the Mekran coast of south-western Baluchistan are also significant.

Regarding oil production in Pakistan, during the latter part of the last century shallow wells were drilled near Lower Eocene seepages in Marri tribal territory of eastern Baluchistan from which a small production was obtained, and very minor quantities have been drawn from other seepages of that province and of the Punjab.

Drilling on more modern lines commenced in 1914 at Khaur in the Attock district of the Punjab, oil being struck in the Siwalik-Murree sequence and, more recently, in the upper part of the Eocene limestone sequence. Other likely structures on the Potwar plateau between Khaur and the Salt Range have been tested and have yielded oil in commercial quantity from the Tertiaries. These fields include Dhulian, Chakwal and Balkassar. From the Khaur and Dhulian fields production reached some 20 million gallons in 1929; in recent years the output has appreciably diminished. As a whole, the results even these producing fields have been relatively disappointing, added to which a number of wholly unsuccessful wells have been drilled, mainly in the Tertiaries of these northern Pakistan areas.

FUTURE PROSPECTS

The production of oil in West Pakistan, and also from the Tertiary rocks of southern Assam adjoining East Pakistan has, therefore, been far below what one might reasonably have expected. This should serve as a warning to those who talk glibly of the occurrence of oil in quantity in the Pakistan dominion. Enterprise in oil production there must still be regarded as very much of a gamble; those willing to undertake the risk are deserving of generous treatment.

At the same time it is apparent that the total potentialities of the region have, as yet, by no means been tested. Exploration of the Baluchistan-Sind area is in its infancy. There the surface evidence indicates the existence of structures, possibly containing oil in commercial quantity, in the outer folds of the Sulaiman belt and in the southern Mekran; the probability of hidden structures beneath the alluvium of parts of the lower Indus area has also been mentioned.

Conditions appear to have been favourable for the formation of oil in certain parts of the south Punjab, Sind, Baluchistan, and Kalat during Lower Tertiary times, and the circumstances of deposition in the Indus region during parts of the Jurassic period suggest the possibility of oil and gas originating in that sedimentary sequence also.

Further north, in the Potwar and Kohat regions, conditions favouring oil formation appear to have existed in the Eocene. In the latter area of the N.-W.F.P., the Lower Eocene limestones that probably succeed the sharply folded Kohat salt deposits in depth have yet to be tested. It is reasonable to assume that the rock salt would form a suitable caprock to any oil existing in the underlying strata.

Finally, in the Salt Range–Potwar area there is the possibility of oil indigenous to the Punjab Saline series, a possibility regarded no doubt as very remote by some who have studied the problem, but not entirely without the chance of success, particularly in view of the relatively simple character of the pre-Tertiary tectonic movements that affected this region.

Pakistan has yet to develop oilfields of a size in any way comparable to those of the important producing countries of the world. Whether it is likely to prove successful in doing so is, at present, quite impossible to predict. As above mentioned, experience in the past has been disappointing; the possibilities of a greater measure of success in the future appear, however, to be sufficiently attractive to justify the gamble of further enterprise.

THE STRATIGRAPHY OF THE ALEXANDRETTA
GULF BASIN*

By CEVAT E. TASMAN

Turkey

ABSTRACT

The Gulf of Alexandretta, or as it is better known in the Near East, the Gulf of Iskenderun, is an arm of the Mediterranean bordering the southern part of Turkey and projecting into the Anatolian mainland. The basin in question is bounded by the Taurus mountains to the north-west and the Amanos ranges to the south-east. The basin and the uplands adjoining it contain a thick section of sedimentary rocks with a distribution covering all the major geological systems ranging from the Silurian to the Quaternary, and totalling over thirty thousand feet. Two-thirds of the section is composed of Tertiary strata, mostly of Miocene age. The Palaeozoic is represented by quartzites and dolomites topped with Carboniferous shales. The Mesozoic is principally in a limestone facies, whereas the thick Tertiary deposits consist of shales, sandstones and conglomerates of neritic and continental origin.

THE portion of the Mediterranean bordering the southern provinces of Turkey and projecting north-eastward into the corner formed by the Taurus and Amanos ranges of the mainland is known as the Gulf of Alexandretta or Gulf of Iskenderun. During the latter part of the Tertiary period it extended further inland transgressing and regressing on the older rocks of the region. During this oscillation back and forth a very great thickness of sediments accumulated. The regression which has been taking place in historic times is evidenced by the records of the biblical period where Tarsus is mentioned as a seaport with moorings for the sailing vessels along its shore. Tarsus at present is an inland city several miles from the sea.

PALAEOZOIC

The oldest rocks of the region are exposed in the Taurus and Amanos ranges and are referred to the Silurian. In the shales associated with the quartzites *Bilobites* and *Dalmanitina?* have been recorded (Frech, 1916; Blumenthal, 1941; Dubertret, 1941-3). This formation in the Amanos ranges is overlain by dolomites and limestones containing *Spirifer verneuili* among other fossils found in it. In the Taurus ranges the dark coloured dolomites and limestones in the ferruginous intercalations contain *Spirifer* and *Atrypa*. The formation is about 1,000 metres thick. It in turn underlies dark grey shales containing bands of fine grained sandstones and limestones. This grey shale series contains *Productus semireticulatus*, *Spirifer* sp., *Zaphrentis* sp. indicating Lower Carboniferous age. The presence of bitumen in this series is an interesting characteristic. The whole of the Lower Carboniferous is between two and three hundred metres thick in the Taurus mountains area.

MESOZOIC

In the eastern slopes of the Amanos ranges grey compact argillaceous limestones represent the Triassic. These limestones with a fœtid odour contain traces of bitumen. Among the few fossils found in them *Naticopsis applanatus* has been identified.

The dark grey limestones forming Djebel Akra on the Syrian boundary form a comprehensive section running from the Upper Jurassic to the Upper Cretaceous. Near the base of the section *Nerinea*

---

* For joint discussion of this and other papers see pp. 68-73.

desvoidyi, and towards the top various species of *Globotruncana*, have been determined. Though no unconformities have been noted detailed studies will probably reveal at least some stratigraphic hiatus in the Lower Cretaceous. Near the Syrian border and in Syria the Upper Cretaceous becomes marly and contains some asphalt which at Kafiriye near Latakia assumes the proportions of a large commercial deposit.

The ophiolitic formation so abundant both in the Taurus and Amanos ranges appears to be of Maestrichtian age. It is observed overlying the greyish and bluish Upper Cretaceous limestones and marls near Ordu and underlying the light brown and yellowish Lutetian limestone of the region.

TERTIARY

The ophiolitic series mentioned does not always have the Eocene limestone above it. On the western slopes of the Amanos, the Burdigalian limestones and Helvetian shales are found overlying the ophiolites.

The Eocene in the region of Amanos is in the limestone facies and contains sporadic evidences of asphalt. It is light yellowish in colour and covers large areas. The foraminiferal content, with several species of *Nummulites*, points to Lutetian age. In the Taurus ranges the Eocene is principally in the flysch facies and is overlain by a limestone of Burdigalian age. The sedimentation conditions appear to be uniform in both the Amanos and the Taurus flanks of the embayment subsequent to the Burdigalian. A very thick section of Helvetian and Tortonian marls, shales, and sandstones overlies the Burdigalian limestone.

The thick Neogene section along the Seyhan river where it is best developed begins with the Burdigalian limestone at the base. This is a grey massive limestone, locally markedly cavernous, generally rich in shell fragments, corals, and other fossils. *Echinolampas*, *Pecten*, *Clypeaster*, and *Flabellipecten burdigaliensis* are among the forms found in this formation. It is 100-150 metres thick and unconformably overlies the Cretaceous and Eocene beds of the Taurus and Amanos ranges. Near the contact with the overlying shales the limestone is quite soft, thin bedded, and somewhat argillaceous.

Overlying the limestone a section about 100 metres thick composed of dark grey shales with calcareous and arenaceous streaks is found. It contains occasional lignites. The sandy and the limy streaks mentioned are more noticeable near the upper and lower contacts. This shale section underlies about 1,000 metres of sandstones and conglomerates, with an unconformity between. The section is more sandy towards the top and is succeeded by a transitional series which is characterized by alternating beds of sandstones, marls, and shales, with a flaggy series at the top.

The most important member of the Neogene is the thick grey shale section overlying the flaggy unit of the Transitional series. The lower part of the formation is dark grey, changing into a greenish grey towards the top. Though it is uniformly and predominantly argillaceous, thin limy and sandy intercalations occur. It is about 2,500 metres thick. It is considered Vindobonian in age on the basis of the following fossils:—

Amusium cristatum	*Clavatula asperulata*
Asturia aturi Bronn	*Conus* cf. *laeviponderosus*
Pecten revolutus	*Voluthilites ficulina*
P. subarcuatus	*Cyprea*, *Turritella*, etc.

This thick argillaceous section is overlain by another transition series. It has a marly zone at the base which is followed upwards by sandstones and conglomerates. The thickness of the formation is of the order of 1,500 metres. It is tentatively placed in the Upper Miocene. The forms identified from the upper sandy member are:—

Arca diluvu Lam.	*Ostrea lamellosa* Brocchi
Cardium sociale	*O. gigensis* Sehl
Conus ponderosus	*Pecten subbenedictus*
Corbula carinata	*Spondylus tenuispina* Sand
Lucina columbella	*Turritella* cf. *cathedralis*
Venericardia	

The formation overlying the above is a marl with sandy and gypsiferous intercalations. At the base large crystals of selenite are characteristic. The selenite grades upward into fine grained gypsum interbedded with grey clay shale, the shale becoming predominant towards the top.

The Neogene section thins out towards Antakya in the east and towards Mersin in the west. In the neighbourhood of Mersin the basal Miocene limestone containing *Clypeaster* is about 100 metres thick, and is overlain by 400-500 metres of dark grey shales intercalated with thin beds of calcareous and marly nature. This in turn is overlain by about 400 metres of chalky limestone which is developed locally in the gypsiferous facies.

Along the Seyhan river the sandstones in the upper part of the Miocene contain such Pliocene forms as *Ostrea lamellosa, Dentalium sexangulare*, together with Tortonian species. The gypsiferous marly beds as well as the crossbedded sandstones appearing above the formation with mixed fauna mentioned are considered Pliocene. About eight kilometres south of Antakya the sandstones and marls containing *Peneroplis, Rotalia*, and *Elphidium* are likewise referred to the Pliocene.

QUATERNARY

An extensive development of " caliche " over a great part of the plain area between the Taurus and Amanos is noticeable. This is a soft and crumbling very porous white limestone. It sometimes includes residual pebbles giving it an appearance of conglomerate. These, together with the fluviatile deposits of the Seyhan-Ceyhan rivers, and the sand dunes along the coastal area, have been deposited after the latest Alpine movements subsided and are referred to the Quaternary.

IGNEOUS ROCKS

Besides the ophiolitic rocks mentioned above as occurring on the Cretaceous and Eocene boundary, the dioritic intrusions on the eastern slopes of the Amanos are of Paleocene age and may belong to the same suite. The basaltic extrusions marking the Dead Sea–Maras graben as well as the flows in other parts are post-Pliocene.

The region is distinctly sculptured by the Alpine orogeny which began during the middle of the Eocene and continued to the end of the Tertiary. After the deposition of the Burdigalian reef limestone regional uplifts brought the limestone above the sea level. In the basin sandy shales with plant fragments were deposited. The limestone reef continued rising more rapidly during the Middle Miocene permitting boulders to be transported by rivers and wave action into the still shallow basin. However, the basin became deeper by the continued uplift of the limestone mass bringing about the deposition of great thicknesses of shale and sandstone during the Helvetian and Tortonian time.

The principal unconformities in this latter period are at the base as well as on the top of the Burdigalian limestone, at the top of the basal shale and at the end of the Pliocene.

Though the intensity of the Alpine movements has all but obliterated the vestiges of the earlier paroxysms, the intensive folding and faulting of the Palaeozoic strata together with the probable continuity of the late Palaeozoic into the Triassic suggests at least that the Variscan phase of the movements has been active in the region.

REFERENCES

BLUMENTHAL, M. 1941. Nigde ve Adana Toroslari. *Metea*, Seri B, No. 6.
——————— 1944. Büyük Çakit Çayi Bogazi. *Turk Cografya Dergisi.*
DUBERTRET, L. 1941–3. *Carte géologique de la Syrie et Liban.*
FRECH, F. 1916. *Geologie Kleinasiens.* Bagdadbahn.
IZGI, M. 1940. Foraminifera from Test Wells at Adana. *University of Texas thesis.*
DE TCHIHACHEFF, P. 1857. *Asie Mineure.*

DISCUSSION OF THE PRECEDING PAPERS BY G. M. LEES, F. R. S. HENSON, A. N. THOMAS, C. A. E. O'BRIEN, E. R. GEE, and C. E. TASMAN

C. E. Tasman asked what was the porosity of the Asmari.

F. R. S. Henson in reply said that the porosity of the fore-reef was variable and could be as much as 30 per cent. The back-reef was non-porous, while the Globigerina beds were finely porous but of very low permeability.

G. M. Lees then added that the results of extensive studies of porosities in the Iraq and Persian fields showed wide variations; some fields had very low porosities. High productivity arose from extensive fracturing. The highest porosity was found at Kirkuk. On the Arabian side primary porosity was more important because fissuring was less. In Kuwait the reservoir rock was sandstone; other fields had porous limestone reservoirs.

J. E. Smith asked whether the Asmari limestone showed any variations in productivity which could be associated with the influence of fracturing, i.e. was fracturing confined to the crests of the structures? Was there any great difficulty due to casing collapse because of the incompetent mobile character of the Lower Fars formation?

G. M. Lees answered that fracturing on the big limestone folds did not follow any constant pattern. About a third of the Masjid-i-Sulaiman anticline was unproductive due to inadequate fissuring. In this case the pitching ends were less fractured than the two flanks, but this was a special and not a general feature.

Casing collapse did not occur, but there were many difficulties in drilling through the Lower Fars group. In some fields very high pressure water shows were troublesome, and thin limestones within the Lower Fars had water under pressures nearly equal to the rock pressure.

W. L. F. Nuttall mentioned that he was interested to hear from Mr. Henson that in Kirkuk a large part of the " Main Limestone " reef had been exposed during Middle Miocene to Eocene times. This was similar to conditions in the " Golden Lane " of Mexico, where the production was also obtained from a reef limestone, which in that case was of Middle Cretaceous age. In the " Golden Lane " the reef had also been exposed for a considerable period of time; in its northern part it was overlain by Oligocene, while in the south the cover included Upper Cretaceous and Eocene sediments. It was thus apparent that in both cases the accumulation of the oil had taken place some time after the cover rocks had been laid down.

Dr. Nuttall also referred to the resemblance between the Bakhtiari formation of south-west Persia and the Siwaliks of western India. In the Himalayan foothill zone there was a marked angular unconformity at the base of the Upper Siwaliks, and he asked whether it had been possible to correlate the unconformity with a folding phase in south-west Persia.

In reply, G. M. Lees stated that there were many points of similarity between the Bakhtiari and the Siwaliks.

He further added that it was doubtful if much of the Asmari oil was indigenous. Some marly zones were found within the Asmari series and these had a low content of bituminous matter which might have yielded oil. But there was abundant evidence of lower oil in the cores of anticlines in wells which had explored the Middle Cretaceous limestones. Below the Asmari the marly limestones and marls of Eocene and Upper Cretaceous age were relatively hard and brittle, and had been fractured by the folding. Consequently they had not acted as cap rocks to seal oil in deeper limestone formations. The oil/water level on the flanks in the Asmari was continuous through the core of the folds. The first core taken from the Middle Cretaceous limestone showed oil in pores and cavities which was believed to indicate a lower oil accumulation since it was below the level of the Asmari edge water, but on test only water was produced. There was thus still some residual oil in the Middle Cretaceous and probably also in lower rocks, but through lack of cover rocks the bulk of the oil had migrated upward into the Asmari where it had accumulated under the impervious cover of the Lower Fars. The shallower fields had surface seepages due to leaks in the cover and it might be that this loss was being made good by slow upward migration from deeper sources through thousands of feet of watered rocks.

J. L. Rich commented on the fact that Mr. O'Brien's paper illustrated the close connection between the problem of oilfield structures and the broader problems of mega-tectonics. References had been made to the " tectogene " concept —a closely compressed symmetrical downbuckle of the earth's crust—as if it were an established fact. Geologists should re-examine this concept very carefully before accepting it and basing their structural hypotheses on it. The concept appeared to the speaker to be wholly fallacious, not only because such a sharp downbuckle seemed mechanically impossible for material such as that of the earth's crust, but also because the consequences to be expected from it did not agree with the conditions observed. The crust should shear across and be thrust upwards long before the tight buckle of the " tectogene " could be formed. Moreover, the Mesopotamian geosyncline, for example, was not in the position expected for a trough within a downward crustal buckle lying under the Iranian plateau, but was far to one side of it; and the geology of the Iranian plateau, so far as he had been able to discover, was totally different from what would be expected if that plateau were on the site of the centre of a " tectogene " downbuckle.

G. M. Lees then remarked that Mr. O'Brien deserved great credit for his stimulating analysis of the Lower Fars problem. His views were not accepted in their entirety by his colleagues, but criticisms referred to details rather than

to general principles. It was difficult to believe that salt could be driven downwards and this conception was contrary to what was known of salt movements, e.g. North Germany. Furthermore, it was possible to explain the structural conditions without involving downward movement of salt.

In contributing to the discussion E. LEHNER said that Mr. O'Brien's new ideas on salt tectonics were fundamentally different from Buxtorf's " Abscherungs " theory. When he went to Iran about ten years ago, he saw " Abscherung " everywhere, not only in the competent group above the Cambrian salt, but also in the cover of the Lower Fars salt. Since then he had begun to suspect that Buxtorf's ideas might require some modification even in the Swiss Jura. He was led to this conclusion by a study of the Punjab Salt Range—Potwar—Hazara region which shewed many similarities with the Jura—Molasse Basin—Helvetic Alps region, but the apparent absence of major thrust sheets in the Hazara Himalayas and Kala Chitta Hills made it very difficult to visualize the superficial transmission of shearing forces across the wide and deep Soan syncline. In the Persian Fars salt province he felt certain that superficial " stripping off " alone could not satisfactorily explain the observed facts. In a northeasterly direction the Lower Fars salt stopped short of the region of major thrusting and the cover of the salt could, therefore, never have been under the pressure of a superimposed thrust sheet. It was also known that the pre-Bakhtiari conglomerate erosion left this cover too weak for the long-distance transmission of any lateral pressure. Lastly, the upturned edges of some of the Middle and Upper Fars syn-clinal outliers, which seemed to float on Lower Fars like inverted empty crab-shells, suggested that they owed their shape to the upheaval of the underlying salt.

Had Mr. O'Brien ever attempted to apply his new ideas to explain the Cambrian salt tectonics or the structure of the Swiss Jura?

C. A. E. O'BRIEN then thanked Dr. Lehner for his kind remarks, and expressed regret that he was not sufficiently familiar with the Swiss salt tectonics to draw a parallel between them and those of south-west Iran. The tectonic problem of the Cambrian salt of Iran was quite different from that of the Miocene since the former was overlain by a strong Competent Series, capable of transmitting forces over considerable distances. The formation of tectonic salt bulges under anticlines in this Competent Series might, however, explain how the Cambrian salt plugs were originally started off on their journey upwards.

Continuing the discussion, G. M. LEES added that Buxtorf's concept of Jura structures seemed to require some modification. O'Brien's ideas were stimulating and would undoubtedly influence thought on problems of relative competence where a salt series was involved.

The Persian area had an embarrassment of possible source rocks. The Eocene, and Upper, Middle and Lower Cretaceous had bituminous zones, through much, though not all, of the mountain belt. The Jurassic where developed as Posidonomya shale was richly bituminous, and one shale sample contained as much as 25 per cent of bituminous matter, but this was exceptional. In some localities the Jurassic and Triassic rocks contained bitumens with very high carbon/hydrogen ratios. Instead of the normal values of 9 to 1 or 10 to 1, they were as high as 22 to 1. These bitumens were infusible and insoluble, and resembled impsonite. Possibly during the passage of time and under deep burial these bituminous rocks had evolved oily vapours leaving these " anthracitic " residues behind. Various speculations had been made on the percentage oil yield from the source rocks which would be necessary to account for the known oil accumula-tions. With thousands of feet of bituminous marls and marly limestone as possible source material only about $0 \cdot 1$ per cent evolved as oily vapours would be needed to form these enormous oil accumulations.

L. DE LOCZY asked for information on the possibilities of source rocks in the older Mesozoic and Palaeozoic formations of the Middle East, and especially in Turkey.

W. B. WILSON enquired whether any of the Persian oilfields were considered to be due to stratigraphical trapping instead of structure.

In reply G. M. LEES said that stratigraphic trap oil accumulations might occur in this great oilfield region, but the developed fields were all due to anticlinal control, and in each case the oil/water level was a horizontal plane through the core of the structure. The Main Limestone of Kirkuk was peculiar in that it differed in age from one end of the oilfield to the other. The important feature was the impervious cover of the Lower Fars series, and the exact age of the reservoir rock was not important. It might be argued that the Kirkuk field was a stratigraphic trap in that the Lower Fars truncated Lower Miocene, Oligocene and Upper Eocene along the length of the anticline, but the trapping effect of this was very subsidiary to that of the anticline itself.

D. SCHNEEGANS asked whether there was a known geological explanation of the regional distribution of the Persian oilfields. He was astonished by the great distance between the fields of Masjid-i-Sulaiman and Naft Khaneh. Was there any explanation of this?

G. M. LEES explained that the zone of foothill folding was broadest in the two embayment areas, that of the Sirwan to the north-west of the Pusht-i-Kuh mountain ranges, and that of the Diz–Karkheh to the south-east. The oilfields of Kirkuk and Naft Khaneh are in the former and the oilfields of Lali, Masjid-i-Sulaiman, Haft Kel, etc. in the latter. In between, the great mountain ranges of Pusht-i-Kuh bulged forward and the alluvial plains extend right up to the mountain front. Because of difficult access and the presence of extensive marsh areas the zone in front of Pusht-i-Kuh has not yet been adequately explored, but there is every reason to believe that there may be hidden anticlines. Exploratory wells are now being drilled in the neighbourhood of Basrah and on the Ahwaz anticline, and eventually the zone between Ahwaz and Naft Khaneh would be explored.

C. E. TASMAN said that with regard to the source beds of the Iran-Iraq fields the choice lay between origin within the Asmari and migration from below. He believed that it was largely a matter of guesswork and confessed that he did not know what were source rocks. For a long time the view was held that dark coloured shales with a high bituminous or organic content were likely source rocks, but the work of Trask and his associates seemed to indicate that neither the colour nor the organic content was a safe guide to source rocks. The only feature that seemed to be characteristic of sediments associated with oilfields was the nitrogen-reduction ratio, a value determinable only in a chemical laboratory and therefore impracticable for use in the field. In the light of all this why was there so much ado about source rocks? He also believed that with the exception of the great quantities of oil, there was nothing among the characteristics of the sediments of the Iraq-Iran-Arabia sector which differed from those of the formations of other areas with much poorer oilfields or no oilfields at all. He agreed with Dr. Lees that the area was endowed with an abundance of oil in the Asmari, Middle Cretaceous or Jurassic, for reasons that were not yet understood so far as source rocks were concerned.

W. B. WILSON added that it was easier to recognize what were not source rocks.

G. M. LEES continued, saying that much research had been done on possible source rocks, but the problem was baffling. In the case of impsonitic rock vapours must have been driven off.

H. G. Kugler then asked whether or not impsonite could occur in a rock containing liquid oil.

G. M. LEES stated that hard brittle bitumen had been observed in calcite veins, and that this was probably an example of an earlier phase of migration.

Another speaker added that there could be an early phase of migration and then cementation.

Next G. M. LEES asked what was the source of the Arabian oil.

W. B. METRE said that he would like to point out that recent work had indicated an important unconformity within the Nari series and that although the Lower Nari was of Oligocene age the Upper Nari was probably almost entirely of Lower Miocene age.

G. M. LEES suggested that Dr. Sahni might have commented on the age of the Salt series.

L. G. WEEKS said that he hesitated to reply to the request for comment on the views expressed by the authors concerning the source rock of the oil in the Tertiary limestone fields of Iran and Iraq, partly because of the very controversial nature of the whole problem of oil origin and accumulation, and partly because of his lack of familiarity with many of the details of the stratigraphy of the Middle East. His knowledge of Middle and Near East geology and its oil occurrences came largely from field reports and the literature, and from two tours of study through those fields and basin areas. It had been his privilege for quite a number of years to make a rather systematized study of the basins and oil occurrences of the world, and he had formed the opinion that a real understanding of the problems of oil occurrence and the key to their solution (in so far as those problems could be solved from the information now available) lay not in a study and familiarity with any one basin area or province, but in a careful empirical analysis of oil occurrences throughout the many basins of the world.

He had seldom listened to three such excellently presented papers as those on which he had been asked to comment about the views expressed on the origin of the oil. He felt that no one could quarrel with the facts of geology so clearly and logically outlined by the authors, but he found it difficult to concur with the views expressed by Dr. Lees and Mr. Henson that the source of the oil in the Oligocene–Lower Miocene Asmari limestone of the Iranian fields and in the Oligo-Eocene so-called Main Limestone of Kirkuk in Iraq most probably lay in the Cretaceous and Jurassic, and possibly in part even older formations down to and including the Cambrian.

A study of the extensive active oil and gas seepages of the Middle East revealed that the vast preponderance, in fact almost all of these, lay in the outcrop areas of the Middle Tertiary oil-bearing formations. These formations carried ample and highly favourable sediments in their deeper basin facies for generating the oil that was now found in the reef and other reservoir type facies deposited in the more aerated waters over the flanks and incipient highs of the depositional basin. If the Mesozoic and even early Eocene sediments provided the oil, why was it that vast outcrop areas of these formations which were exposed by erosion in a great multitude of anticlinal folds over a considerable area were so singularly free of active or live petroleum seepages, if so great a quantity of oil as that stored in the Tertiary originated in them?

Much was made of the fact that these older formations, in their greater part a thick and continuous section of limestone, were bituminous or oil-smelling and carried " vestiges " of hydrocarbons, mainly of solid character. There were many prolific oil-bearing basins in the world in which bituminous oil-smelling strata were non-existent or occurred only incidentally and with no apparent relation to the oil occurrences. And many other instances could be cited at some length of basins with large amounts of highly bituminous strata with no oil, or in which any oil, if present, bore no discernible relation to and was totally incommensurate with the quantity of bituminous matter. Perhaps such bituminous rocks still retained all or a large part of the hydrocarbons formed in them. We were apt to be too much impressed by the potentialities of such rocks as the source of free oil.

He had no doubt, however, that these older strata, of the thick Mesozoic section particularly, furnished much free hydrocarbons. It was known that it contained well developed facies of a character and basin relationship likely to have given free oil. Where ample and very effective cap rocks existed (such as were represented by the anhydrites sealing the great Arabian Jurassic fields, and the shales capping the Middle Cretaceous fields of Burghan (Kuwait) and Bahrein, all on the western basin foreland and hinge belt) this free oil and gas had accumulated in great quantities. Here structure

DISCUSSION

was forming sufficiently early to localize the porous reefs, sands and/or detrital and oolitic limestone and dolomites over these depositional bottom highs adequate to store the large volumes of oil beneath the excellent cap rocks mentioned.

One of the points emphasized by the authors of the three papers was that the folding of the north-east, or mountain front side of the basin, although beginning as far back as Cretaceous time in the remote back areas of the mountains, did not affect the oilfield belt until the Tertiary; and that the main folding of this oilfield belt occurred in late Tertiary and Pleistocene time. He agreed with this general picture. It was a common one, varying with position, along Mesozoic-Tertiary mobile belts. The thick Mesozoic sections indicated that this belt lay near an axis of subsidence. It seemed logical that any free oil developed would have migrated early to higher positions within the basins. There were very many facts which he could not mention in a brief discussion which indicated that oil formed and migrated early. The Pliocene, for instance, which ended a million years or so ago, had as high an incidence of oil occurrences per cubic mile of sediments as any among the best periods of oil-producing sediments. One or two other facts of the many indicating early migration had been touched on in the comments of various people in previous discussions in this section of the Congress. He agreed that various facies of the Mesozoic had generated much free oil. Much of this was accumulated in sealed reservoir facies of similar age to the source beds in various parts of the basin. It was difficult to understand how oil could have been retained in the Mesozoic rocks of a trough area until the advent of Tertiary folding in the quantities required to supply the huge fields.

He did not think that the finding of live oil in the broken pre-Asmari core of structure above the oil-water plane, or the finding of solid hydrocarbons or even traces of fluid oil at greater depth, proved anything with regard to a deep source for Asmari oil. Traces of hydrocarbons of one kind or another may be expected throughout a section such as is present in the Middle East.

Mr. Henson had based much of his case for a deep origin for the oil that had accumulated in the Oligo-Eocene Main Limestone of the Kirkuk anticline in Iraq on the fact that the Lower Fars anhydrite, marl and limestone series of lower Middle Miocene age unconformably overlapped the crest of the Main Limestone arch. It was Mr. Henson's view that if the oil had originated in the deeper basin facies in front of the reefs which form the Main Limestone of the Kirkuk arch, that oil would have been lost during the period represented by the Upper Oligocene—early Miocene hiatus over the area of the structure. This, at least, was a recognition of the principle of early oil formation and migration and it was hardly in harmony with the view that oil was retained in the underlying, unfolded, deep basin section of the Mesozoic until the advent, long after, of the Tertiary folding.

However, viewing the matter in the light of a background study of nearly all of the oilfields of the world, he was not at all concerned about the existence of the hiatus, which Mr. Henson spoke of as precluding any possibility that contemporaneous beds furnished the Kirkuk oil.* In answer to his argument that all of the oil would have accumulated and escaped during the interval represented by the sea regression, quite a number of instances could be cited (such as along the west side of the San Joaquin valley in California) where oil in quantities running up to as much as hundreds of millions of barrels per accumulation lay in beds upturned and open to the grass roots. Except for the more volatile gaseous products, there was actually no more reason for oil to rise above the ground water level than for water to do so. The liquid oil, as was seen in so many instances, had not escaped. It seemed likely that the vestiges of heavy, partly solid, oil found in the Main Limestone to which Mr. Henson referred, represented this type of accumulation.

But there were many other reasons, supported by a world-wide array of surprisingly consistent data, why the hiatus in deposition did not preclude a contemporaneous or pene-contemporaneous source, and did not insure that the oil must have risen from the depths. Space and time permitted presentation of only a little of this impressive and highly significant evidence. In the first place, the great preponderance of the world's discovered oil accumulations, nearly all of them in fact, occurred at or were associated with unconformities. He used the term unconformity in these comments in its widest sense to include nonconformities and disconformities (Kirkuk example) on down to diastems and still lesser breaks in deposition. A study of oil occurrences showed a rather obvious reason for this association of oil accumulation with unconformities. The most natural channels for fluid migration extended outward from the deeper basin sediments along the planes of permeability that merge and open toward the basin flanks and highs of the area of deposition. It was outward toward these higher areas of the depositional area that depositional breaks of all kinds were most pronounced, where they merged and increased in magnitude, and where there existed the winnowed or sorted, effective sands, the reefs, the sorted and porous detrital carbonate rocks, the sorted oolitic limestone lenses, the dolomites, and all of the other bodies of the aerated water bottoms, with effective porosity.

---

* In the somewhat deeper basin Iranian fields the hiatus did not exist, or was of minor time importance. In Iraq it was in considerable part represented by the Upper Asmari and by the anhydrite which separated the Upper from the Lower Asmari over much of the Iranian oilfield belt. In some part the time was represented by the regression, as a result of which the more basinward Lower Asmari of Iran was somewhat younger than the Main Limestone of Kirkuk. In the readvance of the sea the Upper Asmari limestone did not cover much of the Kirkuk structure area. It reached its southeastern part and it overlapped much of Iraq where it was known as the Euphrates limestone. The sedimentation of the Euphrates or Upper Asmari limestone continued upward as the Lower Fars anhydrite, marly shale and limestone sequence. Except for various details, this was essentially the picture as he understood it, and was included as a footnote to aid in following his discussion.

A considerable amount of evidence had accumulated to show that the free migration of fluids, even including gases for any distance across the bedding was not possible in most situations. He, along with perhaps most geologists, had long taken it for granted that oil had had to move up from some deeper source to the reservoir in which we now find it.* He had had to change his views, after an extensive analysis of the evidence, with regard to this broad view of migration. The hydrocarbons did not move upwards as a rule, but they moved laterally up from source sediment facies of con-temporaneous or pene-contemporaneous age in the deeper more stagnant parts of the area of deposition toward the higher aerated areas, which latter were the only places where effective primary porosity could be developed on a sedimentary bottom.

The only places where effective source beds could be deposited was in the relatively deeper, stagnant or quieter waters that lay below effective wave base for the finer sediments and particularly for the effective organic matter which could come to rest only on the quiet bottoms. Likewise, it was only on the stagnant or non-aerated bottoms that organic matter could be preserved for burial from oxidation, aerobic bacteria and the other bottom scavengers. On the aerated bottoms, these scavengers, from bacteria upwards, lived up to the limit of the available food supply, but they could not exist in the more stagnant environments that were found below effective wave base. There was a great difference in the faunas (largely in the benthos) in the aerated environments, where effective primary porosity of all types was developed, from the faunas (largely of the surface or plankton realms) of the relatively deeper stagnant bottom sediments.

Mr. Henson had presented with his paper an excellent picture of the relationship between the Main Limestone reef development, in which much of the Kirkuk oil was stored, and the back-and fore-reef facies. He had showed the change from the aerated bottom reef limestone facies to the organic marl, marly shale or marly limestone facies out in the deeper basin or fore-reef areas. He had given long and careful study to, and he had described very vividly, the extensive, almost complete change in the faunas or bio-facies that accompanied this change in the litho-facies over the depositional areas. He had described a situation which was not peculiar to the Persian Gulf Basin alone, but to many great oil basins and many present restricted sea and gulf bottoms throughout the world. It was a natural and logical situation.

The existence of evaporites (anhydrites and/or salt) in so many stages of the Persian Gulf sedimentation, from the Cambrian to the Miocene, indicated that the basin had been silled repeatedly and for long periods not only during but before and after evaporite deposition. There were many other indications of this partially closed or silled nature besides the presence of evaporites with which he would not deal. In such silled basins the degree of stagnancy requisite for the accumulation and preservation of organic matter was, for various reasons, more readily attained than in more open basins, even below effective wave base in the latter, and it was attained usually at shallower depths.

In further support of the view of Mr. Thomas that the Asmari oil came from a contemporaneous source and in reply to one of the main arguments of Mr. Henson and Dr. Lees, namely, that the oil in the mid-Tertiary limestone could not Fave come from contemporaneous or pene-contemporaneous source facies because of the hiatus separating the Lower hars from the Main Limestone at Kirkuk, he would add that it appeared to him that the oil might not only have come from facies of equivalent age to the reservoir limestone, but that it could in part also have come from deeper basin facies deposited during the interval of the hiatus that extended over the structure and the general reef limestone area. It could even also have been furnished partly by the overlapping Lower Fars series.

The prevailing association of accumulations of oil of all magnitudes, both large and small, with unconformities of various kinds and degrees was in itself very suggestive. Since every bed that was ever laid down led laterally somewhere into an unconformity of some kind, this widespread accumulation of oil at or near unconformities need not be surprising. The partially closed to well-silled nature of the basin, as indicated by the evaporites in the Lower Fars, was also an indication of favourable basin bottom conditions, both before Lower Fars time and during the deposition of the marls, shales and limestones that are included with the evaporites in the Lower Fars series. The Lower Fars series was a direct upward continuation of the Euphrates (Upper Asmari) limestone, which limestone represented much of the interval of the depositional break over the higher areas of the basin bottom in Iraq. An overlap was a favourable world-wide source-reservoir relationship.

Perhaps the thought might arise in reading the preceding paragraph that the Lower Fars could not be a source series because it contained evaporites. He did not agree with this view and he could have supplied much evidence against it had space permitted. Of course the evaporites had not furnished oil, but the associated sediments could very well have done so, as they quite evidently had done in other similar basins. The fact that evaporites were included in the series was no reason why other facies thereof could not have supplied oil. The Lower Fars series was widely petroliferous, and it had abundant seepages and well showings of live oil. It was not just bituminous, a condition which might signify that the rocks still retained all or most of their hydrocarbons in a non-free or pyrobituminous state.

In summary, he believed that there were excellent representatives of source facies associated with the Tertiary oil reservoir facies. These source facies were most closely of the litho-and bio-facies type found in the more richly oil-bearing basins, and they existed in more than ample abundance in Iraq and Iran to supply all of the Tertiary oil in these countries.

---

* He had taken this for granted even though he recognized, as had others, that the oil in the important reservoir that occurred in basement detritus over highs of the basement must have come from overlapping source.

DISCUSSION

The movement of fluids from the deeper basin source facies to the reservoir facies of the basin flanks and bottom high areas of growing structure was facilitated if not entirely controlled by differential compaction pressures of around 100lb. per hundred feet difference of over-burden. So it is quite possible that much of the migration and accumulation of oil in the reservoirs from contemporaneous and pene-contemporaneous facies took place during to well after the deposition of the Euphrates—Lower Fars overlap, and this overlap itself might have supplied quite an appreciable part of the oil. There was evidence that something like two or three thousand feet of overburden accumulated before major oil migration occurred, and that oil moved outward to traps already in existence.

The preceding comments were very incomplete, and much space would be needed to present the vast amount of additional data and examples which could be marshalled in support of the views expressed.

F. R. S. Henson admitted that contemporaneous source rocks were possible, and that the oil could move into stratigraphic traps. Exposure of the reservoir rocks for 35 ml. could have led to oil loss at Kirkuk. Some oil occurred at depth in a Cretaceous stratigraphic trap below Kirkuk. Folding and fracturing took place in late Miocene and Pliocene, and migration resulted from this folding.

ÉTUDE STRATIGRAPHIQUE DU GRANDE FORAGE DE BASTENNES-GAUJACQ (LANDES)

Par J. CUVILLIER

France

ABSTRACT

Ce forage, exécuté par la Société Nationale des Pétroles d'Aquitaine sur le bord du massif triasique de Bastennes-Gaujacq, le plus profond qui été réalisé en France et probablement en Europe, jusqu'à ce jour, a traversé plus de 4000 m. de terrains sédimentaires.

Après les marnes grises du Lutétien inférieur, la sonde a rencontré des marnes et marno-calcaires de l'Eocène inférieur à Alvéolines, Orthophragmines et Nummulites, pour atteindre le Danien vers 400 m. Vers 600 m., le Sénonien supérieur à Orbitoides a été entamé, le faciès à Lagenas y étant largement représenté. La base du Campanien a été traversée vers 850 m. où s'effectue le passage indistinct au Sénonien inférieur; la Turonien, avec des calcaires cristallins à petits Verneuilinidés, passe insensiblement au Cénomanien à Praealvéolines, Miliolidés, Cunéolines, Cyclolines, etc., bien caractérisé à partir de 895 m., avec une puissance de 250 m. environ; ensuite, sur près de 2000 m. d'épaisseur, la sonde a pénétré dans des calcaires marneux ou compacts de l'Albien à spicules de Spongiaires pour toucher, vers 3460 m. les calcaires à Orbitolines de l'Aptien qui était encore représenté à la limite du forage.

GUADALUPIAN FOLDING AND FACIES, TRANS-PECOS TEXAS AND NEW MEXICO

By ROBERT R. WHEELER

U.S.A.

ABSTRACT

Outstanding contributions to Trans-Pecos Permian geology, especially by Phillip King (*Bull. Amer. Assoc. Petrol. Geol.*, April, 1942), differentiated, correlated and dated the unusual variety of Permian facies and investigated the orogenic history of the Guadalupe and other West Texas uplifts.

More detailed surface mapping, however, added new interpretations of the eventful Permian history of the Guadalupe Shelf which forms the northern platform of the western (Delaware) segment of the Permian Basin and exposes most of the Permian sequence producing oil east of the Pecos River.

(1) Following warping and truncation of the Pennsylvanian to Ordovician sequence, the region was overlapped by Lower Permian, Wolfcamp sediments.

(2) The subsequent deposition was interrupted by rejuvenated movements to localize later Permian overlap.

(3) In the Trans-Pecos region the Upper Permian (Guadalupian and Delaware) facies thinned south–westward upon an inferred pre-Cambrian arch west of the present Guadalupe-Delaware Mountain fault zone. Independently, two distinct sedimentary facies developed because of the initiation of the Capitan reef along the margin of the Guadalupe shelf, and its growth into the contemporaneous sediments of the Delaware Basin. Both the sands, dolomites and evaporites of the shelf and the equivalent thick sands and calcareous shales of the basin show this westward thinning.

(4) The Guadalupian rocks were warped into superficial flexures paralleling the underlying reef crests and were cut also by cross-folds.

(5) The latest Permian (Ochoa) evaporite series that filled much of the Delaware Basin locally crossed the Capitan reef and overlapped the Guadalupian shelf, but, due to post-Guadalupian tilting, none of the Ochoa sequence transgressed the reef west of the Pecos. Therefore, of the constituent Castile, Salado and Rustler, even the top of the Rustler lies many hundreds of feet below the Capitan reef escarpment in the tilted western flank of the adjacent Delaware Basin.

(6) Repeated tilting occurred during Ochoa time so that the evaporites thin westward and show unconformities as they thin upon the basinward extension of the Huapache flexure.

GEOLOGIC OUTLINE OF THE PACIFIC COAST OF COLOMBIA, SOUTH OF BUENAVENTURA

By V. OPPENHEIM

Colombia

ABSTRACT

The southern Pacific coast of Colombia appears physiographically and geologically as a continuation of the coast of Choco to the north and the coast of Ecuador to the south. An extensive fault, some 40 to 50 km. east of the Pacific shoreline, separates the Tertiary sedimentary basin from the igneous and metamorphic front ranges of the Cordillera Occidental of presumably Mesozoic age.

The sedimentary belt comprises Tertiary, Upper and Middle Miocene formations, of an average thickness of some 4,000 metres. The sediments are folded into anticlines, and somewhat faulted. The trend of these structures is approximately parallel to the main fault of the coastal belt.

The Miocene is underlain by Oligocene and Eocene strata to the north in the Choco, and presumably Cretaceous limestones and shales occur at the Rio Iro, underlying the Tertiary.

The well-developed sedimentary column, the presence of structures and the occurrence of oil seeps and asphalt outcrops to the north and south of the region under study, make it of interest from the point of view of petroleum geology.

STRATIGRAPHIC CONVERGENCE

By ROBERT R. WHEELER

U.S.A.

ABSTRACT

Stratigraphic convergence occurs through four genetically distinct processes: truncation, onlap, offlap and lateral changes of lithology in time-stratigraphic equivalents. The unappreciated significance of truncation and offlap in creating convergence traps for oil was emphasized recently by Swesnik and Wheeler (*Bull. Amer. Assoc. Petrol. Geol.*, November, 1947). Concepts of convergence have been confused in the literature and evidently in the minds of petroleum geologists who would locate new petroleum reserves faster by a better grasp of the origin of stratigraphic convergence which will account for most future production and which has been inadequately classified from various non-genetic aspects (shape of wedging unit, cross sectional description, reservoir behaviour factors, etc.) or indiscriminately lumped.

Wedging of stratigraphic units by *truncation* implies regional tilting, retreat of seas and differential erosion of the rocks so exposed. Almost always later encroachment of the seas begins with basinal subsidence which tilts the plane of previous truncation and causes shoreward loss of the advancing deposits (*onlap*). Since such transgression cannot be instantaneous, there is a progressive loss of lithological units toward shore. Where such transgression involves much transportable clastics, lithologic facies tend to transgress imaginary time boundaries, as the coarser clastics mantle the overlapped plane of unconformity and successive vertical reductions in grain size are distributed approximately parallel to the tilted sea floor. On the other hand, where clastics are scarce, or the source is distant, or the onlap is gradual, lithological units are deposited essentially parallel to sea level (approximately coinciding with time boundaries), and so give quite a different type of convergence as these units wedge out against the tilted unconformity.

Convergence due to *offlap* is probably rarely observed because of the tendency for truncation of the veneer of beach clastics that follows the retreating sea during tilting or reduction of sea level.

Convergence due to rapid lateral variations in lithology within time equivalents (off-shore bars, channel fillings, reef and bioherm bodies, etc.) is harder to identify but will justify much future study and classification as the structural traps for oil continue to be exhausted.

75

A THEORY OF THE PARTIALLY GASEOUS ORIGIN OF THE FOSSIL FUELS

By J. RONDOT
France

ABSTRACT

Present theories concerning the genesis of fossil fuels are not satisfactory. Thin sections of coal give the idea that the organic debris was at some time impregnated with hydrocarbons, i.e. bituminized.

Flow of liquid bitumens to impregnate the organic debris is unlikely. On the other hand, nothing indicates that the organic matter itself could have yielded through some alteration, all the bitumen which impregnates the debris.

A better theory would be that the bituminization took place through the agency of natural gases from a greater depth. Bacteria probably took part in this phenomenon, e.g. *Bacillus methanicus* or those bacteria found in the primary waters of oil deposits.

Other substances (sulphur) may also have been formed under the influence of natural gases. Methane is to be found not only in connection with oilfields and coal measures (fire damp), but also in sulphur mines (rinchiusiu). This methane would merely be the residue of the gases which were associated with the formation of fossil fuels and of sulphur.

It has been stated that in the vicinity of leakages of coal-gas (methane), organic debris was actually converted into coal or something much like it. Laboratory work on that line would be most desirable.

THE OILFIELD OF GANSO AZUL, PERUVIAN AMAZONAS REGION

By A. HEIM
Switzerland

ABSTRACT

Up to date only one oil field has been developed on the eastern side of the Andes in Peru. This is the Ganso Azul (Blue Goose) field, situated on the Pachitea River, near its junction with the Ucayali, one of the main tributaries of the Amazon. This structure was discovered by Moran who when flying over it in 1928, noted the presence of a clearly defined dome. No seepages are known. A well in the centre was drilled through the Lower Cretaceous shale series, which includes oil sands, and from 1458–3130 feet was in Permian limestone. The oil is of specific gravity 0·75 (42·43°Bé.), and is obtained from depths of about 1,000 feet. Refined products are shipped in iron barrels down to Iquitos and Manaos on the Amazon.

Wildcats elsewhere have not been successful. One drilled at Contamana, on the Ucayali, on a complex dome, encountered the sub-surface structure, but the oil horizon pinched out at the margin of the Brazilian shield.

The entire eastern border of Central Peru has been mapped aerophotographically by the Standard and Shell Companies. Concessions have not been granted by the Peruvian Government. (Compare preliminary report in *Bol. Oficial Dir. Minas y Petroleo, Min. Fomento*, Lima, Sept., 1947.)

DISCUSSION

J. V. HARRISON stated that bands of fossiliferous rocks occurred in the Red Beds along the river Perene, and these yielded Senonian fossils as compared with the Eocene forms found to the east of Ganso Azul by Dr. Heim. This locality was more than 100 miles to the south.

V. C. ILLING expressed doubts about the Ganso Azul oil being primary.

N. H. FISHER asked if Dr. Heim would define the nature of the gap between the Permian in his section, and whether he had found signs of an angular erosional unconformity anywhere in the area.

A. HEIM replied that there was conformity between the beds.

L. KEHRER observed that in Venezuela Upper Palaeozoic rocks were found only in the Andes and the Sierra de Perija. They were Upper Carboniferous to Lower Permian in age, and were transgressively overlain by the Jurassic formations or by the Lower Cretaceous. In most places, however, they had been eroded after the Hercynian Variscan orogeny, and therefore he considered the oil prospects of the Palaeozoic beds of Venezuela to be poor.

L. OWEN commented on Dr. Heim's belief that the Ganso Azul oil originated in the Lower Cretaceous sandstones in which it was found. He thought that the light gravity of the oil strongly suggested that it had reached its present position by migration through channels of capillary dimensions. During such migration the oil would tend to lose its heavy components by selective filtration.

SOME OUTLINES ON THE TECTONICS
OF THE UPPER AMAZON EMBAYMENT

By W. RÜEGG and D. FYFE

Peru

ABSTRACT

That portion of Peru lying East of the Andes was affected by various tectonic movements at different times, resulting in the present picture of a widely folded, thrusted and probably block-faulted region.

Chief among the orogenies were the Palaeozoic and late Tertiary paroxysms which generally led to strong tilting and thrusting in this sector of the present Andean Cordilleras, and to more gentle surface crumpling on conjectured mobile blocks or block-systems in the easternmost spurs of the Cordillera Oriental.

An important feature of this basin is the occurrence of large stratigraphic gaps revealing both conformable and angular contacts between the Lower Cretaceous beds and underlying formations which are usually much older. An attempt is made to explain such phenomena, by the difference in age, mobility and position of the individual blocks.

There are also many data on the lithological characters of the formations present and brief notes on their respective facies types.

I. UPPER UCAYALI-URUBAMBA REGION

(*a*) *Boquerón del Padre Abad.*—This region is situated west of the Río Ucayali, lying on the highway between Tingo Maria and Pucalpa. As a whole it is strongly folded and faulted, and in the Boquerón gorge the main fold is a complex zone consisting of a sequence of Upper Triassic and Liassic limestone (Santiago Formation) forming the core of the structure, followed by the Boquerón sandstone and conglomerate series of Jurassic, very probably Kimmeridge-Tithonian age, by Cretaceous sandstones and shales, and the Tertiary Red Beds (Rüegg, 1947).

The entire section is steeply tilted and overturned towards the east, the core showing strong thrusting in the same direction with slices and wedges squeezed away. On the eastern limb there are various steep to vertical faults with displacements presumably of considerable stratigraphic throw, involving all formations, *viz.*, revealing fault or thrust contacts of the Santiago formation with the Tertiary Red Beds, etc. Strong tectonic distortion and disintegration conceals the relationship between the individual series, but it is likely that there exists some angularity between the Mesozoic formations though these depositional contacts were not examined in detail.

(*b*) *Ganso Azul Field–Sira Mountains.*—As known from the Ganso Azul Well No. 1 there exists apparent concordance between the Permian fusulinid limestone and the overlying Cretaceous sediments, the dip being absolutely unaltered and flat throughout. This may hold good for the nearly level culmination plane of the dome while conditions might be different downflank.

In the northern portion of the Sira Mountains (Aymeria creek, etc., east of the lower Pachitea river) the investigations corroborated the presence of the supposed structural and stratigraphical concordance found in the Ganso Azul field. Here thick and coherent exposures of greyish Carboniferous limestone are normally overlain by blue and black limestone layers of very probably Jurassic age which in turn are followed by the Agua Caliente sandstone and shale assigned to the Neocomian. There is no evident change in dip and strike in this section, except that a very thin pebble bed is observed resting on top of the blackish limestone indicating a short erosional stage before the Cretaceous was deposited.

(*c*) *Río Urubamba.*—Very striking is the section of vertical beds marvellously exposed in the Pongo de Mainique where Devonian (?) graywacke is in straight, clean-cut contact with Permian

FIG. 1.

limestone, and this in turn with some Cretaceous sandstone and the Tertiary Red Beds (Heim, 1948). Here the different gaps are by far greater than at Ganso Azul and definite field evidence excludes any pseudo-concordance or faulting, and may indicate a one-time folding of the entire sequence in youngest Tertiary times. Such a hiatus with no distinct structural disconformity would thus tend to prove that no decided movement of the area or block covering the region between Ganso Azul and the Río Urubamba, except perhaps gentle emergence and submergence, had taken place before the violent Pliocene or " Quechua " folding.*

II. CONTAMANA HILLS AREA

The Contamana Hills lie some 25 kilometres east of the town of that name and range north-west—south-east, approximately parallel to the Ucayali river. They form a sharp westward facing ridge with elevations of 300 to 450 metres above the level of the surrounding low rolling jungle plains. They extend from about 7° S. Lat. to 7° 30′ S. Lat., and from about 75° 05′ W. Long. to 74° 45′ W. Long.

The Contamana Hills represent in their present form a recent structural uplift with steep dips on the west flank—20° to 45°—and dips of 2° to 10° on the east flank. They constitute, therefore, a long curving, very asymmetrical anticline, upon which have been imposed four distinct domes slightly offset *en échelon*. There is no such fractured monoclinal structure with north-south faulting present as mentioned in his rapid reconnaissance by V. Oppenheim (1937).

Between the Ucayali river to the west and the main Contamana uplift there is a low secondary fold, covered completely by Tertiary Red Beds. To the east of the main anticline, at a distance of about 26 kilometres, lies the axis of the shallow syncline—Sabalo depression—between the Contamana Hills upwarp and the Contaya High.

There is little doubt that the Contamana Hills and the Contaya Dome belong to the same structural unit, or block.

In the Contamana Hills proper the following sequence of rocks is encountered in exposures, from top to bottom:—

(1) Sugar Sandstone—Upper Cretaceous, which encircles the uplift completely;
(2) Chonta Shale—Turonian-Coniacian (to Santonian?), chiefly sandy gray shales with fossiliferous localities; and
(3) Sandstones—Mainly Neocomian, passing into Cenomanian, which make up the cores of the structures and are eroded quite deeply in the centres of the stratigraphically higher domes.

The Cia. Peruana de Petróleo " El Oriente " Well Rayo No. 1, located on a closed dome at the northern end of the hills, penetrated the Lower Cretaceous and encountered only a very thin section of shale, non-marine in all probability, representing the interbedded shale and sand series of the producing horizon in the Ganso Azul wells. Since B. Kümmel (1946) found this shale body well developed in his Cushubatay section, there is little doubt as to the rapid thinning of the shales towards the east, *e.g.*, there is accurate proof of a fundamental lateral change of favourable marine conditions into a predominantly continental barren facies type as believed typical for such epicontinental environments.

After drilling through a small section of the Boquerón (Chapiza) formation of Jurassic age, the well passed into a basic igneous rock, of which over 100 feet was penetrated. At the contact of the Cretaceous with the Boquerón a definite increase in dip occurred confirming Kümmel's observation

---

* There is a known tendency to conceive each stratigraphic gap as an indication of an " unconformity," while a break in a sequence may simply be explained by non-deposition of individual beds or entire formations in a continuous marine environment. This phenomenon is rather common and the sedimentary incompleteness can be originated by even deep scouring currents, vertical circulation, etc., according to the changes in the chemical and physical properties of the waters concerned. Moreover, an hiatus may be caused by non-sedimentation—emersion and erosion without preceding folding—and also by epeirogenic movement—emergence, denudation and subsequent immersion—thus indicating always a disconformity and not an unconformity. Consequently, all these conditions can account for preventing sedimentation over wide areas and since these features are characteristic of epicontinental seas, of marginal parts of geosynclines, etc., they, therefore, may certainly also occur in the Amazon Basin.

of a decided unconformity between these formations in the aforementioned Cushubatay area 100 kilometres to the west.

Above the igneous rock was encountered some true quartzite. Samples from the igneous material collected at different depths were analyzed and determined to be a syenodiorite (Johannsen classification 2, 2, 11 P), similar to an occurrence from the adjoining Territorio do Acre (Moura and Wanderley, 1938). From chemical changes in the constituents of the rock it was believed that it had been subjected to a long period of weathering. It was therefore assumed by some geologists that the old and deeply disintegrated surface of the Brazilian shield complex had been struck. This assumption is logically open to speculation and doubt, since one of the samples said to show strong weathering was from a core taken at least 100 feet (30 metres) below the top of the igneous material (Rüegg, 1947).*

III. CONTAYA REGION

The Contaya region was visited by a Commission of the Peruvian Government headed by Douglas Fyfe as chief geologist in 1943. Except for some palaeontological results (Newell and Tafur, 1943) there is nothing published on this remote area which stands out as a very hilly and rugged country of young topography in the midst of the great Amazon basin and lies between the upper reaches of the Río Tapiche (erroneously shown as the Río Blanco on the Loreto sheet, B-18 of the 1 : 1,000,000 map of the American Geographical Society), and the Río Ucayali, its centre being approximately 65 kilometres north-east of the town of Contamana (see preliminary map of Peru, Bol. No. 1, *Inst. Geol. Peru*, 1945).

The area examined by the expedition within the Contaya Dome was comparatively small and lies on the main north-south axis of the immense uplift, some 20 kilometres south of the north-westward plunging outcrop of the Sugar Sandstone, which forms a complete oval-shaped rim-rock around the dome with axes 60 kilometres by 40 kilometres. Inside this rim-rock, in the areas of pre-Cretaceous, numerous cross-folds, which diverge remarkably from the younger more or less north-south trending system of structures, can be distinguished by stereoscopic studies of aerial photographs.

(A) *Stratigraphy.*—The following stratigraphic sequence was established in the area surveyed:—

(1) Palaeozoic. (a) Quartzitic sandstone, 50 metres to 100 metres exposed, Cambrian to Middle Ordovician;
　　　　　　　　(b) Shale series, 150 metres to 200 metres, Middle Ordovician (Chazian-Normanskill);
(2) Cretaceous. Sandstone complex, several hundred metres, representing the Neocomian or Agua Caliente series, the Chonta and Sugar Sandstone formations;
(3) Mainly Tertiary. Red Beds, fairly thick, however less than towards the west, probably mostly or entirely Tertiary, and
(4) Plio-Pleistocene. Clays, gravels, occasionally terraces.

(1) *Palaeozoic*

(a) Quartzitic Sandstone. The oldest strata, discovered in deeply entrenched cañons, are greyish and brownish quartzitic sandstones consisting of a highly cemented fine silica matrix with coarser grains interspersed. Some outcrops have the appearance of true quartzites and seem to be affected by some metamorphism probably due to circulating hot waters. This formation is well stratified in flags one half to one metre thick, and where seen was dipping gently to the north. Only the top of the series was observed and no fossils were found in it, but by analogy, that is to say by its apparent conformity with the overlying Ordovician shales and its similarity to beds in the same stratigraphic position, it seems reasonable to infer a tentative Cambrian to Middle Ordovician age (Steinmann, 1930; Ahlfeld, 1946).

(b) Shale Series. Superimposed on the quartzitic sandstone and conformable with it there is a series of true clay shales showing no metamorphism; when wet, the shales are dark blue and slippery. This formation, named " Contaya " by D. Fyfe, is crowded with graptolites, trilobites, brachiopods, cephalopods, and ostracods, and was determined to be Middle Ordovician age (Lower Chazian-Normanskill) by Newell and Tafur (1943). The upper surface of the Palaeozoic is very strongly and unevenly denuded throughout.

---

* According to G. Rozanski the hypothesis of hydrothermal alteration should be considered.

(2) *Cretaceous*

Separated from these Palaeozoic beds by a striking hiatus and in decided unconformity, both in direction and angle of dip, which is plainly visible, there is a sequence of very coarse-grained, massive, cliff-forming, buff to mottled sandstones, several hundred metres thick, succeeded by a small thickness of thin-bedded white sandstone intermixed with impure grey and cream coloured shales which are followed by typical exposures of the Sugar Sandstone. The lower massive sandstones resemble the Lower Cretaceous or Moa Sandstone Formation from the adjacent Acre Territory (Oliveira and Leonardos, 1943; Moura and Wanderley, 1938), and are thus the lithologic and time equivalent of the Pongo, Hollín, and Agua Caliente sandstone (Singewald, 1927; Wasson and Sinclair, 1927; Moran and Fyfe, 1933).

Although there is a topographically low area forming a ring around the Contaya dome, inside the Sugar Sandstone rim, a low which is characteristic of the Chonta shale outcrop (often denominated the " Cretaceous Shale Interval " of Turonian to Santonian (?) age) very little true shale exists in the area, and it is obvious that the Chonta in the Contaya region is almost completely lacking in its shale and limestone components as found to the west, and is represented only by thin, cream-coloured sands with a very small proportion of shale.

There is evidence of a local overlap of the Sugar Sandstone across the outcrop of the beds occupying the " Cretaceous Shale Interval " in the eastern portion of the dome. This overlap is seen clearly in aerial photographs and was noted in the field.

(3) *Mainly Tertiary Red Beds*

As in the Ucayali, Pachitea, and Huallaga regions, the Red Beds consist of a repeatedly alternating series of sands, sandstones, clays, intercalated with a few fossil layers, poorly consolidated and current-bedded, and of reddish, green to variegated tints, including some lenses or streaks of semi-compact conglomerates, nodules of clay and ironstone, flags of calcareous and carbonaceous matter, gypsum, and salt.

These clastics lie parallel to or with a slight overlap on the known Cretaceous and exhibit laterally and vertically the unstable fluctuations as displayed in a sedimentary basin of rapidly changing conditions. In several localities, directly above the Sugar Sandstone, it is likely that they contain at least some marine lenses or interfingering outlets belonging perhaps to the uppermost Cretaceous.

(4) *Plio-Pleistocene*

Unconformably above the Red Beds there is found in many places a capping of badly sorted, fossiliferous soft clays, silts, and lignitic beds and sometimes extensive gravel terraces. These accumulations are usually horizontal or slightly tilted and once occupied large regions. Older horizons of these deposits are assigned to the Pliocene of the post-Quechua folding showing rather freshwater habitat, and the formerly different basins and estuaries are said to have merged to the east and northeast into a relatively distant open sea (Gardner, 1927; Greve, 1938; Maury, 1937).

Such older clastics together with more recent ones are found at varying elevations above the present base level of the rivers, and it is obvious that some portions of the Amazon embayment are undergoing warping.

(B) *Tectonics of the Contaya Region.*—Field observations show clearly that the Ordovician is truncated by the Cretaceous, and that there is a remarkable divergence in strike and dip between the two groups involved. This indicates that the area suffered an early folding and then stood out of water probably until the commencement of the Cretaceous. It is conjectured that subsequent to this old orogeny further disturbances with possible blockfaulting occurred, resulting in a definite landmass, the Contaya High, and which would account for the absence of the Carboniferous in these strongly uplifted regions, and for the presence of Carboniferous-Permian deposits in tectonically differently situated areas, or blocks, such as is the case in the nearby Territory of Acre, the northern Sira Mountains and regions of the Urubamba river (Moura and Wanderley, 1938; Moran and Fyfe, 1933; Heim, 1948).

F

As evidenced by the intersection of the major structure with minor domes and anticlines, the Contaya area has been affected by two principal systems of folding. The first occurred before the Cretaceous was laid down, possibly during the Caledonian paroxysm, and formed a series of structures with axes more or less at right angles to the axis of the main north-south dome which originated during the late Tertiary movements.

IV. GENERAL REMARKS ON TECTONICS

(a) *Notes on the Contacts between the Cretaceous and the Underlying Formations.*—It is interesting to note the varying unconformities between the base of the Cretaceous beds and the underlying formations of entirely different ages, as cited in the following paragraphs. Nothing could demonstrate more clearly the widespread hiatus which existed before the Cretaceous which was then laid down in fairly consistent sequence over the entire eastern Peru.

In the Ganso Azul Well No. 1, fossiliferous Permian limestone was encountered directly below the Neocomian sandstone. The contact between the two marine formations is apparently conformable. This conformity in spite of the extraordinary gap is to be explained by non-movement in this particular block during considerable time.

The Rayo Well No. 1, at the north end of the Contamana Hills, drilled through the Neocomian sandstone into the eastern pinch-out of the transgressive Boquerón (Chapiza) formation of the Upper Jurassic. At the contact an abrupt increase in dip was found. This would indicate some structural movement between the time of the deposition of the Boquerón and the Cretaceous beds. The marked unconformity between these formations in the Cushubatay area as already reported, makes it appear that this movement is not merely a local one.

From these and combined field data we deduce that there are conformities and unconformities present between the Lower Cretaceous and the underlying formations, all of which seems to point out that we are dealing with local and frequently changing conditions in the different parts of the Peruvian Orient as is shown in the following table, where the Lower Cretaceous is found lying on beds of various ages:—

Locality	Formation	In Contact with	Particulars (dip and contact)
Boquerón del Padre Abad	Neocomian	Boquerón (Chapiza)-Upper Jurassic	Steep to overturned; probable slight unconformity.
Ganso Azul No. 1, Río Pachitea	Agua Caliente sandstone (base)	Permian fusulinid limestone	Smooth; no apparent change in dip.
Río Aymeria-N Sira Mts.	Agua Caliente sandstone (base)	Jurassic? limestone resting on Carbon. limestone	Medium angle dip; no unconformity seen.
Pongo Mainique-Río Urubamba	Tertiary Red Beds	Devonian? graywacke followed by Permian limestone and Cretaceous	Vertical dip; all contacts absolutely parallel and clean.
Rayo Well No. 1, NNW Contamana	Neocomian	Boquerón (Chapiza)-Upper Jurassic	Abrupt increase in dip; apparent unconformity.
Río Cushubatay and Sarayacu	Neocomian	Boquerón (Chapiza)-Upper Jurassic	Decided unconformity in dip and strike.
Middle North Contaya uplift	Neocomian	Middle Ordovician	Marked unconformity in dip and strike.

The table illustrates that the Neocomian sea flooded areas which had suffered considerable breaks in the sequence, being in places tremendously peneplained, and that indisputable conformities as well as definite unconformities are present, independent of the fact that both conditions are found on uplifts generally. For a plausible explanation of these features, apart from the probability that there exist pseudo-conformities and erosional contacts locally, we have to visualize the problem from another viewpoint: namely, it is universally known that the great zones of folding cannot be dealt with and understood without the supposition of enormous fluctuations and dislocations within and beneath the basement complex.

Applying such a thesis to our problem in the East Peruvian Basin and taking into consideration the questions brought up by the tabulated facts, we would like to suggest that many of the more superficial and shallow masses have either been crumpled and tilted in mobile, alternate blocks, or left perceptibly unmoved in more rigid ones. In the course of further development later transgressive formations overlapped these blocks of different age, structure, mobility, and position and therefrom resulted, according to the block concerned, a conformable or an angular deposition.

(b) *Folding and Faulting.*—Although there is still much knowledge lacking, some data collected to date concerning the main features of the different systems of folding and faulting are reviewed in the following resumé, providing a provisional definition of some of the tectonics of the East Peruvian Basin.

The earliest orogeny possibly belongs to the Caledonian or pre-Devonian system of folding (Taconic or younger phase), which affected the Lower Palaeozoic as in the Contaya area.

After the deposition in certain geological milieu of the Permo-Carboniferous beds—Acre Territory, Sira Mountains, Río Urubamba—further disturbance is suggested, representing probably some phase of the young Palaeozoic or Variscan diastrophism, most likely in the form of deep-seated block-faulting, comprising large areas.

There is conclusive evidence that the Upper Jurassic was folded in the region of the Río Cushubatay and the Rayo Well No. 1 at the northern slope of the Contamana Hills (young Kimmerian folding?), which occurred very possibly between the Kimmeridgian-Portlandian and the Lower Cretaceous. This convulsion and resulting unconformity are no doubt regional.

The " Peruvian " folding, according to Steinmann, which is well established in the Central Andes at the end of the Cretaceous, as well as the " Incaic " paroxysm in early Tertiary times (which are equivalents of the Laramide Revolution, and some intra-Paleocene orogeny, respectively), were of minor importance in the basin area of the Upper Amazon, if indeed they affected it at all.

It is most probable that in one area which includes the Ganso Azul, Northern Sira, and part of the Río Urubamba regions, there was little if any folding of the Palaeozoic formations previous to the Pliocene movements, and there exists apparent structural conformity with the overlying Cretaceous and, in fact, with the Tertiary beds, although there are enormous stratigraphic breaks. No major displacements occurred in these sectors until the late Tertiary.

Indeed, the most decisive event in the tectogenesis of the Peruvian Orient is the all-round active Andean or " Quechua " folding of the early to mid-Pliocene, which overshadows and probably blurred to a great extent all previous movements. Its final stage has probably not concluded yet.

Enormous masses were mobilized during the various phases of this process; yet, it must be emphasized that vulcanism in general shared but indirectly in the folding movements, whereas these latter had a very decisive bearing on the magmatic injections and eruptive activities. From the strata involved it became obvious that this orogeny affected the sedimentary groups in their entire thickness, and it is apparent that extraordinary accumulations were moved over a deep-seated thrust plane and have then been compressed, pushed up and thrusted against the Amazon foreland, forming a series of asymmetrical, partly overturned folds from west to east.

During this revolution the old crystalline shield served as a buttress, and the thrusts became checked before reaching the present Ucayali river. The easternmost structures of the Cordillera Oriental—Contamana Hills and Contaya High—show, therefore, no imbrication, thrusting and violent folds any more; they originated mainly by renewed differential rise and surface crumpling of the mobile block, or block complex, and represent but fading repercussions of the major Andean uplift. Thus the fundamental structure in large areas is paratectonic rather than Alpine.

PART VI: THE GEOLOGY OF PETROLEUM

REFERENCES

ADAMS, J. I. 1908. An outline review of the Geology of Peru. *Ann. Rep. Smithson. Inst.*

AHLFELD, FR. 1946. Geología de Bolivia. *Rev. Museo La Plata*, 3, Geol. no. 19, 370 pp. La Plata.

BERRY, E. W. 1937. Late Tertiary Plants from the Territory of Acre, Brasil. *The Johns Hopkins Univers., Stud. in Geol.*, no. 12, pp. 81–90. Baltimore.

BRANNER, J. C. 1919. An outline of the Geology of Brasil. *Bull. Geol. Soc. Amer.*, 30.

CABRERA LA ROSA, A. 1932. Notas sobre la Geología y Geografía del Valle del Río Santiago. *Rev. Cienc.*, 35, nos. 397–402, Extracto, pp. 1–21. Lima.

CHASE, PH. W. 1933. The Geology along the Perenne and Tambo Rivers of eastern Peru. *Journ. Geol.*, 41, pp. 513–526.

CIZANCOURT, H. DE. 1933. Tectonic Structure of Northern Andes in Colombia and Venezuela. *Bull. Amer. Assoc. Petrol Geol.*, 17, no. 3, pp. 211–228.

DOUGLAS, J. A. 1921. From the Port of Callao to the River Perene. *Quart. Journ. Geol. Soc.*, 77, pp. 246–284. London.

GARDNER, JULIA. 1927. A recent collection of Late Pliocene Invertebrates from the headwaters of the Amazon. *Journ. Washington Acad. Sci.*, 17, pp. 505–509.

GERTH, H. 1938. General outline of the geological history of the South-American Cordillera. *Bol. Geol. y Min.*, 2, nos. 2–4, pp. 1–10. Caracas.

GREENE, R. G. 1939. Oil on Agua Caliente Anticline, Loreto, Peru. *Bull. Amer. Assoc. Petrol. Geol.*, 23, no 5, pp. 688–691.

GREVE, L. 1938. Eine Molluskenfauna aus dem Neogen von Iquitos am oberen Amazonas in Peru. *Abhandl. Schweiz. Paleont. Ges.*, 61. E. Birkhäuser & Cie., Basel.

HARRISON, J. V. 1943. Geología de los Andes Centrales en parte del Dept. de Junín, Perú. *Bol. Soc. Geol. del Perú*, 16, pp. 5–97. Lima.

HEIM, ARNOLD. 1947. Croquis tectónico del campo de Ganso Azul, Río Pachitea, Perú: con una contribución por W. Rüegg. *Bol. Dir. Min. y Petrol.*, 26, no. 79, pp. 51–62. Lima.

———— 1948. El Perfil transversal Apurimac-Urubamba. *Bol. Inst. Geol. del Perú*, no. 10. Lima.

KNECHTEL, M. M., RICHARDS, E. F., and RATHBUN, M. V. 1947. Mesozoic Fossils of the Peruvian Andes. *The Johns Hopkins Univers., Stud. in Geol.*, no. 15, 150 pp. Baltimore.

KÜMMEL, B. 1946. Estratigrafía de la Región de Santa Clara. Estudio preliminar. *Bol. Soc. Geol. del Perú*, 19, pp. 133–152. Lima.

LISSON, C. I. 1925. Como se generó el Suelo Peruano. *Bol. Soc. Geol. del Perú*, 1, pp. 97–126. Lima.

McLAUGHLIN, D. H. 1925. Geology and Physiography of the Peruvian Cordillera, Departs. of Junin and Lima. *Bull. Geol. Soc. Amer.*, 35, pp. 591–632.

MAURY, CARLOTA, J. 1937. Argillas fossiliferas do Pliocenio do Territorio do Acre. *Bol. Serv. Geol. e Min. do Brazil*, no. 77. Río Janeiro.

MORAN, R. M., and FYFE, D. 1933. Geología del Bajo Pachitea. *Bol. Of. Dir. Min. e Indust.*, 12, no. 41, pp. 43–54. Lima.

MOURA, P. DE, and WANDERLEY, A. 1938. Noroeste do Acre, reconhecimentos geologicos para Petroleo. *Bol. Minist. da Agric., Serv. Fom. Prod. Min.*, no. 26, pp. 1–176. Río Janeiro.

NEWELL, N. D., and TAFUR, I. 1943. Ordovícico fosilífero en la Selva Oriental del Perú. *Bol. Soc. Geol. del Perú*, 14–15, pp. 5–16. Lima.

OLIVEIRA, A. I. DE, and LEONARDOS, O. H. 1943. *Geología do Brasil.* 2a Ediçao, Rio Janeiro, 813 pp.

OLSSON, A. A. 1942. Some tectonic interpretations of the Geology of NW–South America. *Proc. Eighth Amer. Sci. Congress*, May, 1940, 4, pp. 401–416. Washington.

OPPENHEIM, V. 1937. Geological Exploration between Upper Juruá River, Brazil, and Middle Ucayali River, Peru. *Bull. Amer. Assoc. Petrol. Geol.*, 21, no. 1, pp. 97–110.

———— 1943. Geología de la Sierra de Cucutú, Frontera Perú-Ecuador. *Bol. Soc. Geol. del Perú*, 14–15, pp. 104–121. Lima.

PILSBRY, H. A. 1944. Molluscan fossils from the Río Pachitea and vicinity in eastern Peru. *Proc. Acad. Nat. Sci. Philadelphia*, 96, pp. 137–153.

RICH, J. L. 1945. Oil Possibilities of South America in the light of regional geology. *Bull. Amer. Assoc. Petrol. Geol.*, 29, no. 5, pp. 495–563.

RÜEGG, W 1947. Estratigrafía Comparada del Oriente Peruano. *Bol. Soc. Geol. del Perú*, 20, pp. 57–100. Lima.

SINGEWALD, J. H. 1927. Pongo de Manseriche. *Bull. Geol. Soc. Amer.*, 38, pp. 479–492.

———— 1928. Geology of the Pichis and Pachitea Rivers, Peru. *Bull. Geol. Soc. Amer.*, 39, pp. 447–464.

———— 1937. Discussion on V. Oppenheim's publication: Geological exploration between Upper Juruá River, Brazil, and Ucayali River, Peru. *Bull. Amer. Assoc. Petrol. Geol.*, 21, no. 10, pp. 1347–1351.

STEINMANN, G. 1922. Die junge Hebung der Kordillere Südamerikas. *Geol. Rundschau*, 13, pp. 1–8.

———— 1923. Umfang, Beziehung und Besonderheiten der andinen Geosinklinale. *Geol. Rundschau*, 14, pp. 69–82.

STEINMANN, G. 1930. *Geologie von Peru.* Carl Winters Univers. Buchhandlung, Heidelberg.

STILLE, H. 1936. Entwicklung des amerikanischen Kordillerensystems in Zeit und Raum. *Sitz. Ber. Preuss. Akad. der Wissensch.*, 25, pp. 134–156.

STAPPENBECK, R. 1927. Über Transgressionen und Regressionen des Meeres und Gebirgsbildung in Südamerika. *N. Jahrb. f. Mineral., etc.*, Beil. Bd. 58, pp. 453–496.

TSCHOPP, H. 1945. Bosquejos de la Geología del Oriente Ecuatoriano. *Bol. Inst. Sudamer. d. Petrol.*, 1, no. 5, pp. 446–484. Montevideo.

WASSON, TH., and SINCLAIR, J. H. 1927. Geological Explorations East of the Andes in Ecuador. *Bull. Amer. Assoc. Petrol. Geol.*, 11, no. 12, pp. 1253–1277.

DISCUSSION

R. A. SCHLUMBERGER said : " Si mes informations sont exactes le degré géothermique est tout-a-fait anormal dans la région bordière orientale des Andes peruviennes, et en particulier dans le champ pétrolifère d'Agua Caliente. Je demande a l'auteur si des précisions peuvent être données à ce sujet."

R. R. WHEELER remarked that the differences of view-point expressed by Dr. Heim and Dr. Harrison (speaking for Mr. Rüegg and Mr. Fyfe) regarding the magnitude of the Lower Cretaceous unconformity, raised again the problem of the measurement of unconformities: (i) should they be evaluated on the local magnitude of the discordance in dips above and below? or (ii) should the missing sequence be a measure of the importance? or (iii) should the areal extent of the regression and subsequent transgression of the sea be the critical factor? In this case the magnitude of the Cretaceous-Permian unconformity was evidently very great, whereas the local (apparent) concordance of the strata was unimportant. How much of the pre-Cretaceous sequence mappable was truncated across the region studied?

THE ATLANTIC COASTAL PLAIN

By H. W. STRALEY III and HORACE G. RICHARDS
U.S.A.

ABSTRACT

The writers review the stratigraphy of the Atlantic Coastal Plain of the United States between New Jersey and Florida. This summary is based on both geological and geophysical studies, the second author being largely responsible for the geological data and the first author for the geophysical information. Particular attention is given to information recently brought to light by a study of samples from deep water wells and oil tests in the region. The relation of the geology to the petroleum possibilities of the Atlantic Coastal Plain is also discussed. The writers are of the opinion that the Atlantic Coastal Plain cannot be written off as a potential source of petroleum until further exploration and studies have been made. There are four areas that deserve more adequate testing; (1) the Berlin-Salisbury embayment in Maryland, (2) the Pamlico Sound basin in North Carolina, (3) the Beaufort basin in South Carolina, and (4) the Okefenokee basin in south-eastern Georgia and north-eastern Florida. Southern Florida and south-western Georgia are not considered in this paper, since those regions have closer affinities to Gulf Coast and Cuban geology, and therefore constitute separate problems.

INTRODUCTION

ABOUT the beginning of the Second World War interest developed in finding oil on the eastern coast of North America. Alabama, Florida, Georgia, and the Carolinas were therefore invaded. Two failures in Pierce County, Georgia, and one in Nassau County, Florida, damped activity; but it was probably the Sunniland, Florida (1943), and Gilbertown, Alabama (1944), successes that brought renewed progress. Three wells have been drilled in Maryland, 12 in North Carolina, 21 in Georgia, and more than 40 in Florida since new activity began. During this period interest was kept alive by the Geological Society of America, which aided Horace G. Richards, and the American Association for the Advancement of Science, which subsidized H. W. Straley, III.

GEOLOGY

The region bears striking resemblance to both the Gulf Coast and the Appalachians. The sedimentary formations are those of the Gulf, but most structural features are related to Appalachian trends.

New Jersey.—The formations appearing in New Jersey range in age from Raritan (basal Upper Cretaceous) to Cape May (Upper Pleistocene). Basement rocks, which outcrop on Long Island and at Philadelphia, slope, in general, south-eastward at about 14 metres per kilometre. Towards the coast their gradient increases markedly. There is no direct evidence of their depth along the Jersey coast, but a 700-metre well at Atlantic City bottomed in Upper Cretaceous. Woollard and others suggest a depth of about 1,525 metres at Avalon, south of Atlantic City. Troughs in the basement were filled with sediment in Triassic time, and may be traced intermittently from the Highlands to the Delaware River.

No commercial oil or natural gas has been found in New Jersey.

Delaware.—The geology of Delaware is similar to that of New Jersey with only the Pleistocene outcropping, except along the Chesapeake and Delaware Canal, and a few other places.

Maryland.—Maryland has unique features. A depression in the basement, beginning at the present coast, extends through Berlin and Salisbury almost to Washington. All formations thicken in this area, and Triassic sandstone and shale underlie Lower Cretaceous. Richards has named this feature the Salisbury Embayment (Fig. 1). The Monmouth-Matawan (Navarro-Taylor, upper Upper Cretaceous) thins southward, whereas the Raritan (Tuscaloosa, basal Upper Cretaceous) thickens and becomes more marine.

Three recent wells have been drilled without encountering oil or gas.

The gradient of the surface of the basement complex changes eastward, as elsewhere. Seismic work indicates that the slope is very low under Chesapeake Bay, whereas it is about 9 metres per kilometre between Salisbury and Ocean City.

Virginia.—The Cretaceous is conspicuous in Virginia, especially the Patuxent formation of the Potomac group (Lower Cretaceous). Monmouth-Matawan has pinched out and Raritan is reduced to 21 metres in thickness. Midway (Paleocene), Pamunkey (Claiborne-Wilcox, Eocene), and Jackson (Upper Eocene) thicken north of James River. Cederstrom attributes this thickening to faulting.

The basement surface slopes seaward at about 6 metres per kilometre from the fall zone at Petersburg, but the gradient changes at 33 kilometres off-shore, so that it may be 3,700 feet below tide at a distance of 100 kilometres from the present coast. Alexander, MacCarthy, Prouty, and Straley recorded a similar change in gradient in South Carolina, as did Johnson in north-eastern North Carolina, not far from the Virginia border.
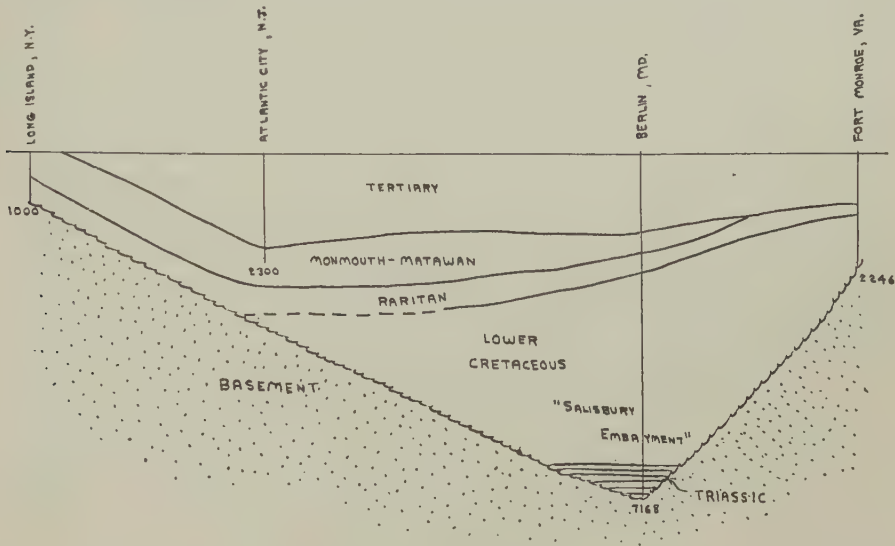
FIG. 1.

North Carolina.—The Cretaceous outcrops in a wide band along the Carolina Ridge, but is buried farther north (Fig. 2). It is difficult to distinguish between Upper and Lower Cretaceous, both of which thicken toward the coast between the Dismal Swamp and the Carolina Ridge. Marine faunas from both have been identified from wells in the Cape Hatteras–Cape Lookout area. Peedee (Navarro, Upper Cretaceous) and Black Creek (Taylor, Upper Cretaceous) outcrop south of the Neuse River, but pinch out against the Carolina Ridge and the Fort Monroe elevation (Fig. 4).

The unconformable Eocene pinches and swells in a similar manner.

The basement surface, although irregular, slopes toward the sea, with the same sharp increase in gradient noted elsewhere. From the fall zone to Beaufort, Cartaret, and Washington counties, the gradient is not far from 2 metres per kilometre. From that longitude seaward, it is far sharper. Geophysical work indicates that it steepens west of Fort Landing, Swanquarter, and Elizabeth City.

Peneplanation of the basement was far from complete. Johnson indicates a low ridge west of Edenton and Plymouth, with a valley between it and the fall zone. Other features are open to the same interpretation. In Pitt County, at Fountain, granite comes to the surface from a depth of about 60 metres under adjacent farmlands. Such topographic irregularities may be covered by superincumbent strata and compacted into plains-type folds. One cannot, therefore, deny the possibility of petroleum in local traps of this nature.

Several unsuccessful deep tests have been drilled in post-war years.

The Standard Oil Company of New Jersey drilled the most important test near Cape Hatteras. The total depth was 3,351 metres. The last 25 feet was in crystalline rock which was penetrated at a depth in excess of that predicted.

In 1935 and 1936, under a grant-in-aid from the American Association for the Advancement of Science, MacCarthy and Straley conducted geomagnetic investigations on the Carolina Ridge. They observed a series of anomalies elongated subparallel with Appalachian tectonic trends. They thought it probable that the source of the anomalies plunged south-westward. They attributed them to either structural conditions (lithologic variations) or topography in the pre-Mesozoic basement.

A notable feature of the North Carolina Coastal Plain is the basin between the Dismal Swamp and the Carolina Ridge at Cape Fear.

The Carolina Ridge may be interpreted in terms of topography or structure. The basement rises at Wilmington to within 425 metres of the surface, and extends north-westward toward the Piedmont at an equal or greater elevation.
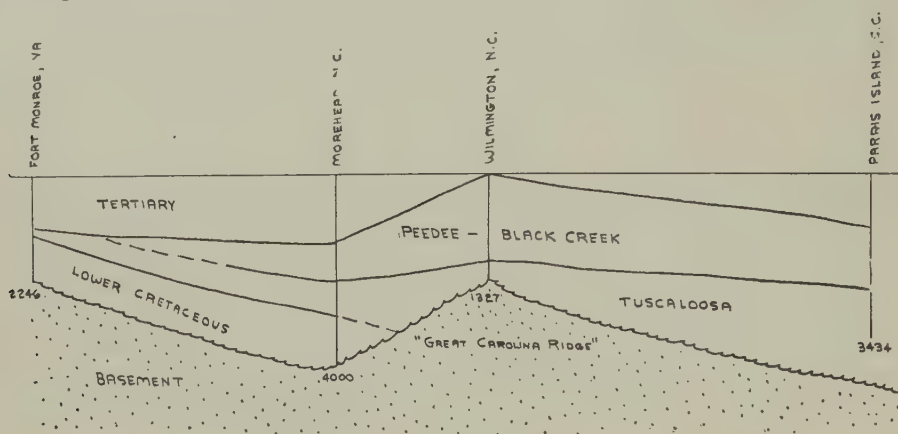
FIG. 2.

South Carolina.—With the exception of the Flint River (Oligocene) near the Savannah River, South Carolina surface geology is similar to that of North Carolina. The presence of Triassic basins buried under Cretaceous and later sediments is indicated. At both Florence and Summerville, wells have penetrated what some workers interpret as Triassic sandstone similar to the Newark series. At the latter locality a black, diabasic, igneous rock resembling sills of Triassic basins has been encountered.

Alexander, MacCarthy, Prouty, and Straley have thought that geomagnetic work near Florence outlined a basin trending north-east–south-west or subparallel with other Triassic basins south of the Potomac. A magnetic anomaly trends subparallel with other Triassic basins extending from north-east of Summerville nearly to Walterboro, and this feature includes the sites of two wells that penetrated Triassic (?) at depths of the proper order.

Geophysical work over much of South Carolina has given rise to interesting interpretations. The presence of buried Triassic basins has been mentioned. South-east of the Summerville Triassic basin lies an anomaly that occupies the position assigned to the Beaufort basin. North of the Santee River reconnaissance indicates another basement elevation or intrusion. Likewise, both geophysical and deep well data indicate that Conway lies over an eminence in the basement rocks.

Several wells have been drilled in the Beaufort basin.

Richards has suggested the possibility of off-shore oil, 50 kilometres seaward. One of the most likely areas appears to be in the Atlantic extension of the Beaufort basin.

North of the Santee River, several anomalies trending subparallel with known Cretaceous structures in Cuba and Florida may be observed. The largest of these, just north of the river, trends roughly east-west. It was well down the northern flank of this anomaly that the 1938 Williamsburg County well was drilled. If the anomaly represents a tectonic feature, none of the wells in northern South Carolina were drilled on the most likely structure.

Georgia.—The surface geology south of the Savannah River is not significantly different from that to the north. All of the chief formations from the Tuscaloosa (basal Upper Cretaceous) to Pamlico (Pleistocene) outcrop. In the subsurface there are significant differences. The Tuscaloosa becomes
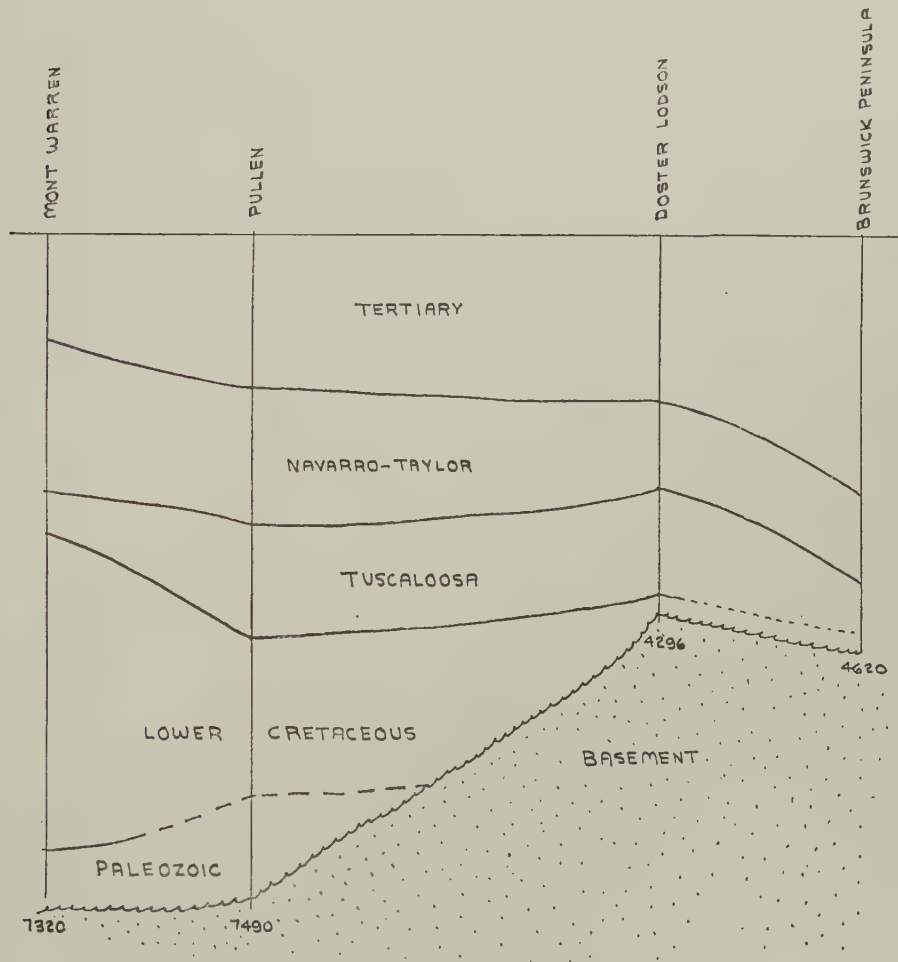
Fig. 3.

more marine south-westward from the Central Georgia Uplift (Figs. 3 and 4). Non-marine Comanche appears beneath the Tuscaloosa and thickens westward. Marine Jurassic, present in Clarke County, Alabama, may underlie south-western Georgia.

There are several structures of interest. On the west the State is bordered by the Decatur arch that follows the trend of the Chatahoochee River. The Central Georgia Uplift (Fig. 4), which is related to the Ocala Uplift of Florida, and may be a northern extension of one of its branches, separates the

Atlantic Coastal Plain from the East Gulf Coastal Plain. A physiographic feature, Trail Ridge, which trends roughly north-south just east of the Okefenokee Swamp, has been interpreted as structural, perhaps another branch of the trifurcated Ocala Uplift.

Florida.—The general deepening of the basement continues southward. At Hilliard, Nassau County, Florida, questionable Paleozoic rock was encountered at 1,128 metres. Farther south, in Dixie County, definite Lower Paleozoic sediments were met at a depth of 1,110 metres. This occurrence can probably be correlated with the Ocala Uplift. A recent well drilled near Cedar Keys, Levy County, reached Middle Paleozoic shales at a depth of 1,791 metres. Farther south the basement is considerably deeper. Wells more than 3,500 metres in depth in the Sunniland field, in the southern part of the State, had not reached basement at their total depth.
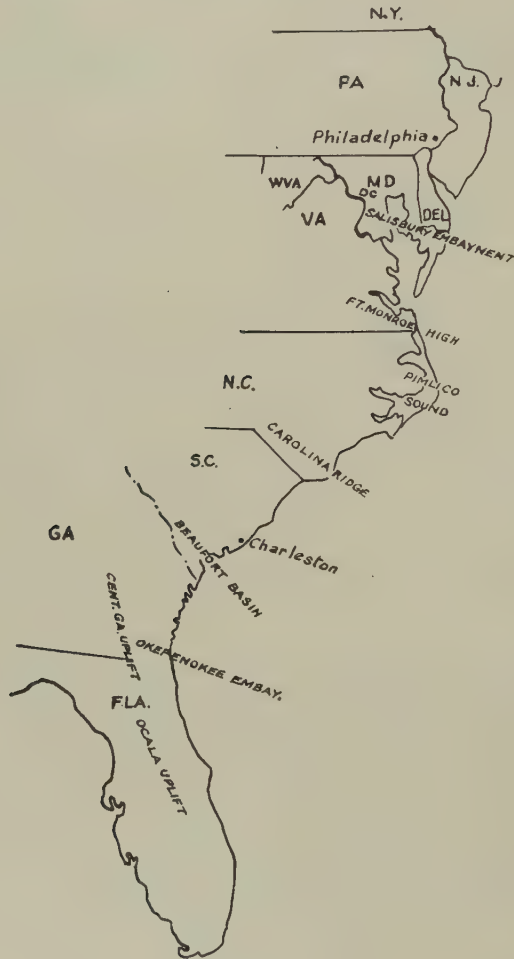

FIG. 4.

Structurally the State is divided by the Ocala Uplift. To the south-west of this great feature, which traverses the State from Osceola County (near the east coast in the latitude of Tampa) north-westward to its two (or three) termini in Taylor, Hamilton (and Nassau) counties, lies the southern Florida basin. In the western Florida panhandle lies the Apalachicola Embayment through which passes the Decatur Uplift of Alabama and Georgia. The Okefenokee Embayment (Fig. 4) lies north-east of the Ocala Uplift with its centre near Jacksonville.

CONCLUSIONS

The writers are of the opinion that the Atlantic Coastal Plain cannot be written off as a potential source of petroleum until further explorations and studies have been made. There are four areas that deserve more adequate testing: (1) the Salisbury Embayment in Maryland, (2) the Pamlico Sound basin in North Carolina, (3) the Beaufort basin in South Carolina, and (4) the Okefenokee basin in south-eastern Georgia and north-eastern Florida. Southern Florida and south-western Georgia are not considered in this paper, since these regions have closer affinities with Gulf Coast and Cuban geology and, therefore, constitute separate problems.

REFERENCES

EWING, M., and VINE, A. C. 1939. Geophysical investigations in the emerged and submerged Atlantic coastal plain, part III, Harnegat Bay, New Jersey section. *Bull. Geol. Soc. Amer.*, 50, pp. 257–296.

EWING, M., VINE, A. C., WOOLLARD, G. P., and WORZEL, J. L. 1946. Recent results in submarine geophysics. *Bull. Geol. Soc. Amer.*, 57, pp. 909–934.

JOHNSON, W. R., JR. 1938. Geomagnetic reconnaissance of the coastal plain of north-eastern North Carolina. *Bull. Geol. Soc. Amer.*, 49, p. 1951.

MACCARTHY, G. R. 1936. Magnetic anomalies and geological structures of the Carolina coastal plain. *Journ. Geol.*, 44, pp. 396–406.

————, PROUTY, W. F., and ALEXANDER, S. A. 1933. Some magnetic observations in the coastal plain area of South Carolina. *Journ. Elisha Mitchell Sci. Soc.*, 49, pp. 20–21.

———————— and STRALEY, H. W. III. 1937. Magnetic anomalies near Wilmington, North Carolina. *Science*, 85, pp. 362–364.

———————— and ————————. 1938. Geomagnetic reconnaissance of the Carolina coastal plain. *Bull. Geol. Soc. Amer.*, 49, p. 1953.

RICHARDS, H. G. 1945. Subsurface stratigraphy of the Atlantic coastal plain between New Jersey and Georgia. *Bull. Amer. Assoc. Petrol. Geol.*, pp. 885–955.

———————— 1947. The Atlantic coastal plain, its geology and oil possibilities. *World Oil*, 127, p. 45.

———————— 1948. Studies on the subsurface geology and paleontology of the Atlantic coastal plain. *Proc. Acad. Nat. Sci. Philadelphia*, 100, pp. 39–76.

WOOLLARD, G. P. 1941. Geophysical methods of exploration and their application to geological problems in New Jersey. *Bull. N.J. Dept. Cons. and Develop.*, 54.

———————— 1943. Geological correlation of areal, gravitational and magnetic studies in New Jersey and vicinity. *Bull. Geol. Soc. Amer.*, 54, pp. 791–818.

DISCUSSION

After reading the paper on " The Atlantic Coastal Plain " on behalf of Mr. H. W. Straley and Mr. H. G. Richards, R. R. WHEELER addressed the following questions to R. B. Campbell: (i) What were the favourable aspects so far revealed by test wells on the Atlantic Coastal Plain? Shows of oil or gas? Thick porous reservoir rocks? Evidence of source rocks? (ii) Was it significant that whereas the Gulf Coastal Plain adjoined a basin that was a favourable collecting area for organic (source) material, the vastness of the Atlantic Ocean basin was unfavourable for a concentration of fine-grained, most easily transported source material?

In reply R. B. CAMPBELL stated that tests in the Cape Hatteras (North Carolina) area had revealed a marine section regarded as favourable. In this connection it should be noted that a well near Salem, New Jersey, although very near to the outcrop, found brackish water in Cretaceous formations. The feature of exploration in the Florida–Georgia area of greatest interest, at least to paleogeographers, had been the discovery of Paleozoic formations, predominantly black shales, under the Mesozoic and Tertiary. This placed a south-eastern boundary to the land-mass " Appalachia," hitherto regarded by many as extending far out into the Atlantic.

C. L. MOODY stated that geophysical work had been carried out over most of the Atlantic Coastal Plain from Salisbury, Maryland, down to and into areas of the Gulf Coast plain which produced oil and gas. Favourable structures were rare.

The possible genetic relationship between oil and the thick Mesozoic limestone of the Gulf Coast plain threw an unfavourable light on the petroleum prospects of the Atlantic Coastal Plain, because these limestones were believed to be absent in the latter area. Apart from this adverse suggestion the province should not be regarded as impossible prospective territory.

AIR SURVEY AND GEOLOGY

By T. D. WEATHERHEAD

Great Britain

ABSTRACT

1. *The Advantages of Air Survey as a Method of obtaining Information for the Geologist.*
   (*a*) The photograph as a mathematical document from which maps and plans with contours can be made.
   (*b*) Large areas can be covered in a short time.
   (*c*) Detailed information can be obtained.
   (*d*) Information from photographs is objective.

2. *Flying and Photography.*
   The survey aircraft; navigating devices used; radar and radio aids to navigation; the air survey camera, lenses and filters.
   The method of taking vertical photographs, the scale of vertical photographs and the uses of various scales for exploratory and detailed investigation.
   Oblique air photography and its use in geological studies.

3. *Mapping from Air Photographs.*
   Ground control for air survey; different methods used according to nature of topography. Technique in production of medium and small scale plan maps without contours.
   Brief description of the Wild A.5 and A.6 stereo-plotting instruments, and Williamson-Ross S.P.3. Multiplex, used in the preparation of contoured maps and plans.

4. *Photographic Mosaics.*
   Method of construction of uncontrolled and controlled mosaics. Their application to geological study; their use in studying formations over large areas and for showing the inter-relationship of structures, which cannot be appreciated on the ground.

5. *Photographic Interpretation.*
   Stereoscopic vision and basic principles of interpretation of air photographs and the importance of tone and texture on the photographs. The use of photographs by geologists in the office and in the field. The preparation and use of uncontrolled photo-geological maps.

6. *Air Survey and Aerial Magnetometer Surveys.*
   The application of aerial photography and photogrammetry to aerial magnetometer surveys.

AIR survey has been used by geologists for many years in the exploration and development of mineral and oil resources all over the world. Although its general application is fairly widely known, the advances in technique and equipment made during the war years are not so widely appreciated. This paper attempts to set out the basic principles of modern air survey technique and to indicate the most important ways in which it can be applied to the many problems of the geologist and development engineer.

The main advantages of air survey can be outlined as follows:—

(*a*) An air photograph is a mathematical document on which it is possible to measure distances and heights accurately, and from which accurate plans and maps with contours can be produced.

(*b*) It is a very rapid method of obtaining information.

(*c*) The air photograph provides an over-all view of the earth's surface and records it in detailed form. By this means the inter-relation of various features can be detected, which often cannot be appreciated on the ground.

(*d*) The air photograph provides a great amount of detail of value to the specialist.

(*e*) The information obtained from air photographs is objective. Once the photographs have been taken the information can be re-checked without undue trouble.

Air survey should, therefore, be considered as an additional tool to assist the work of the geologist. In no case does it entirely supplant work previously carried out by ground methods, but it can reduce the amount of ground work very greatly, and in many ways can provide information which cannot be obtained on the ground.

The stages in which air survey can be utilized by the geologist and development engineer can be outlined in general terms as follows:—

(a) By employing small scale photography in the exploratory stage, hundreds of square miles can be photographed in a few hours. Mosaics can then be made which give a pictorial representation of thousands of square miles on one photograph. The individual photographs can be used for stereoscopic examination of any particular part. From this preliminary study the areas worthy of more detailed examination can be chosen.

(b) For more detailed geological study of limited areas medium scale photography is necessary. This can also be used for the preparation of topographical maps suitable for the planning of roads and sites for camps, etc.

(c) The third stage concerns chiefly the development engineer, when large scale plans with or without contours are needed for the detailed planning of housing layouts and refineries, etc.

The specifications for each job will vary according to the type of country and the purpose of the photography. The type of aircraft, camera, lens, filter, scale of photography, time of year and many other factors have to be carefully related to the final answer that is required. It is usually more economical to take photographs which will satisfy the precision requirements of air survey.

There are two main requirements regarding the type of aircraft. For reconnaissance and exploratory photography the aircraft must fly as high as possible—at least 20,000 feet—in order to obtain small scale photographs. This necessitates the aircraft being fitted with oxygen, with an endurance of at least six hours; it must also be comparatively fast. For large scale photography which is required for large scale mapping in the development stage, a comparatively slow flying aircraft at a low altitude is required.

All survey aircraft must be modified so that the air photographer has a good view of the landscape below, to either side and ahead of the aeroplane, so that once the starting point has been located it is not lost to view as the aircraft is brought round on to course. In order to navigate the aircraft over areas which are unmapped or inadequately mapped it is necessary to divide the country into blocks and photograph strips which can then be used as photographic maps on which to navigate. Although radar and radio aids are undoubtedly the methods of the future, they are at present uneconomical for the normal sized area to be photographed. The actual photography is carried out in parallel lines of flight, the photographs being taken at intervals so that there is a 60 per cent overlap in the forward line of flight and approximately 30 per cent overlap between the parallel lines of photography. This is essential for the mapping processes that are used, and to enable any part of the area to be studied stereoscopically.

As most air photographs are liable to be used for mapping, the air camera has to be constructed to the high precision necessary for accurate mapping. The British camera is the Williamson O.S.C., using a negative size 9in. × 9in. and a magazine holding 500 exposures. It is fitted with a between-the-lens shutter, and the whole camera is enclosed in a perspex spherical dome into which hot air is passed to retain the camera at a normal temperature and humidity, as otherwise electrical discharge on the film may occur and distortion of the negative be introduced. Although the film camera is satisfactory for most types of work, for the production of very large scale plans it is better to use glass negatives, as all dangers of distortion which are inherent in film are then reduced to the minimum.

There are two main types of air photographs—those taken with the camera in a vertical position and those taken pointing obliquely at the object. The oblique photograph provides the more familiar view and, therefore, is valuable in illustrating areas to people unfamiliar with the vertical view. For most geological work the vertical photographs, which can be studied stereoscopically, are of more value than obliques. Since they present the plan view the whole layout of structures can be seen, while

on oblique photographs the view is a perspective one and a certain amount of the topography is hidden. The oblique photograph, however, can by the angle of its view sometimes show the details of structures which are not visible or cannot be definitely identified on vertical photographs.

Vertical air photographs are always taken with a forward overlap of approximately 60 per cent —the same point on the ground is therefore photographed from two different positions in the air. When the pair of photographs are studied through a simple binocular stereoscope, each eye sees a slightly different view of the same object. These two different images are fused in the brain to form a three-dimensional picture. The stereoscopic impression is due to the slightly different position occupied by features relative to one another in the two views. In this way the illusion of relief is created, which is the basis of all interpretation and mapping from air photographs.

The scale of the photographs will be determined by the use to which they are to be put. For reconnaissance surveys, where the chief purpose is to study the main geological formations of an area a scale of 1/40,000 to 1/62,000 is satisfactory. For detailed study of an area a scale of about 1/20,000 is required. For large scale plans a scale of 1/3,000 or 1/5,000 may be necessary. Vertical photographs should be taken as nearly vertical as possible as, apart from producing eye strain on the observer, a tilted photograph will produce distortions in the stereoscopic image which may lead to false interpretation.

With the aid of a roll inductor compass the pilot is able to keep the aircraft on a true and constant heading for as long as required. Auto-pilots are also used to eliminate the gradual deterioration in the standard of flying which is inevitable in long photographic sorties flown by a human pilot.

The value of a radio or radar aid lies in two main points. Firstly, its ability to ensure a standard lateral overlap between parallel lines of flight and to guarantee complete coverage. Secondly to determine the position of the aircraft in space and thus to provide co-ordinate values to points located on the photographs, thereby dispensing with a considerable amount of ground control. Application of these aids, however, is complicated by the fact that the necessary accuracy is only possible over a limited range, and it is unlikely that networks will be found covering the areas to be surveyed. The movement and installation of stations in the outlandish parts of the world where these surveys are usually carried out is a laborious and costly business, and would only be economically worthwhile for very large areas.

There are three main types of lenses used, the choice of the lens depending again on the purpose of the photography. The 6-inch lens is normally used for exploration surveys and topographical mapping, as by using this lens the altitude at which the aircraft is to fly is reduced to the minimum, and the wide angle view produces the greatest sense of relief in the stereoscopic model.

It is important to choose the correct filter to produce the best photographic quality over the particular type of country to be surveyed. The geologist can often assist the air photographer in obtaining the best result by giving him information as to the predominant colours of the rocks and vegetation in the area to be photographed.

If the photographs are to be used for constructing a photographic mosaic it is important that photography of adjacent areas is taken at approximately the same period of the day so that the shadows are similar. Mountainous areas should be photographed around mid-day to reduce the shadows to a minimum, and flat areas during the early or latter periods of the day so as to let the shadows accentuate what relief exists. The time of the year for photography will be largely determined by the weather conditions.

All photographs for accurate mapping must be related to survey triangulation points, the co-ordinates of which are known, and if contours are to be drawn, to certain control points the height values of which are known. In areas where there is ample topographical detail the most satisfactory method is to complete the photography first, select the points for which co-ordinate and height values are required and then carry out the ground control. In countries where there is little or no topographic detail, such as barren desert, it is necessary to make artificial marks on the surface of the desert, large enough to show on the photographs.

In order to prepare a medium or small scale plan map of a reasonably flat area a technique known as the slotted template method is employed. This is a mechanical version of the old radial line system. A grid is laid out on to which are plotted the positions of the triangulation stations. Points of detail are chosen on each photograph, and a template cut so that slots are made in the direction of each chosen point of detail or minor control, each slot being radial from the centre of the photograph. Since all the photographs in the forward line of flight overlap each other by 60 per cent the centre points of three photographs will show on each one, and the minor control point is intersected by three slots or rays. By this means the exact position of that point is fixed, the general result being a great number of subsidiary control points in complete sympathy with the triangulation control. With the minimum of triangulation points provided by normal ground survey methods, data for an accurate plan map of a large area can be rapidly compiled.

To appreciate fully the advantages of air survey it is important to understand the practical difficulties of carrying out this work by ground methods alone. In many areas transport is difficult if not impossible, and the season during which the climate is suitable for ground survey is limited.

Perhaps the greatest advance in air survey technique has been the ability to produce accurate contoured plans and maps from air photographs. This is certainly one of the most important ways that air survey can assist the geologist and the development engineer. An accurate topographical map is essential to much of the geologist's work. The development of an oilfield or mining area will entail the choice of the best routes for roads, sites for camps, and other buildings. By studying the air photographs stereoscopically it is possible to decide which are the best sites for camps, etc.; and from the photographs the contoured map can be drawn, which is the basis for all subsequent work. Many are the examples where roads and railways have been built along uneconomical routes because the area had not been adequately surveyed in advance. The air photograph, by providing an over-all view of the area in three dimensions, presents at the outset all the possibilities for a projected route.

Accurate contoured plans and maps can be produced from air photographs with the aid of modern stereo-plotting instruments. This is not the place to describe in great detail the method by which this is carried out, but a brief description will be of interest to those who have not had the opportunity of seeing these machines.

The Wild A.5 plotting instrument is designed to establish the conditions at the instant of exposure. On either side of the instrument are skeleton cameras which correspond to the positions of the camera in the aircraft when the exposures were made. Into these are placed the two photographs, which are then studied stereoscopically through the binoculars. By adjusting the position of the two cameras the two photographs are mutually orientated so that a perfect fusion is obtained over the whole area of the stereoscopic model under examination. The next stage is to relate the two photographs to the ground control points, the plan and height values of which are known. A mark visible in the optical system can be moved in one plane through the model, and by moving the foot pedal can be moved in a vertical plane. By means of an accurately geared mechanism the movement of the mark in the optical system is synchronized with the movement of a pencil on the drawing table.

It is thereby possible to set the mark at a point on the photograph for which the true plan and height value is known, and by moving the mark around the photograph and keeping it just touching the surface of the ground to draw a contour on the map.

Assuming that the necessary standards of accuracy have been maintained in the flying, photography, and processing of the film, it is possible with these instruments to draw contours at 5-foot intervals. Plans up to scale of 1/1,000 can be produced by the same means—so high is the precision of this instrument. One of the great advantages of the Wild A.5 is its ability to extend the triangulation on small scale photography from the first pair of photographs for which ground control data are available over a series, thus minimizing the number of triangulation points that have to be surveyed on the ground.

A great deal of the cost and difficulty in preparing maps by ground survey methods is taken up by the establishment of the control. Air survey reduces the amount of work that has to be done on

the ground to a minimum. It is, therefore, possible to arrange to carry out the ground control during the most suitable season, and the plotting is carried out in the office under the best working conditions.

The Wild A.5 therefore fulfils two main functions. On the one hand it is able to produce very large scale plans with contours suitable for engineering and detailed development schemes, and secondly to extend triangulation control. After this has been completed, the photographs are passed to a basically similar but simpler instrument, the A.6, with which it is possible to plot the detail and the contours on each pair of photographs.

Another type of mapping instrument that is used for the preparation of maps with contours is the Multiplex, or as the English version is known, the Williamson Ross S.P.3. This instrument is based on the Anaglyph principle of projecting one photograph through a red filter and the other through a blue filter and studying the image through compensating spectacles fitted with similar coloured lenses and thus seeing the image stereoscopically. A small table equipped with a pin-point of light in the centre can be moved through the three-dimensional model, and adjustments made to its height above the plotting table.

A pencil is fitted exactly underneath the pin-point of light which draws on the plotting table every movement made with the table. Thus, as in the A.5, the mark in the optical system is moved to points on the photograph for which the plan and height values are known, so in the S.P.3 the pin-point of light is moved to similar positions on the photographs, and the details and contours drawn out. It is also possible with this instrument to bridge a number of photographs from one group of control to another.

Another method of presenting information which can be of great value to the geologist and development engineer is in the form of photographic mosaics. As the work implies, a photographic mosaic consists of a number of separate photographs joined together to make one complete photograph of a large area. Assuming that the difference in relief is not too great, a mosaic can be constructed to be almost as accurate as a map by rectifying the individual photographs to the detail on a map or other control that may be available, and then laying these rectified photographs down on to the control. For areas where there are no adequate maps or control the photographs can be fitted together as accurately as possible to make an uncontrolled photographic map of the area.

The uses and advantages of photographic mosaics are two-fold. Firstly a photographic mosaic or photo map shows considerably more data than a map. It will, for example, show the details of land use and surface features which are not shown on maps. The areas under cultivation, villages, parts that are being eroded by wind or water, etc., will be visible. In the areas where there is little surface vegetation, the geomorphology of an area is clearly shown on a photographic mosaic. The different rocks will often be indicated by different tones on the photographs.

The second use and advantage of a photographic mosaic lies in the fact that it is possible by this means to view an area of perhaps several hundred square miles in extent at once and on one photograph. This makes it possible to study the inter-relationship of geological structures and to see a pattern in a complex area which would be quite impossible to appreciate on the ground.

In the oil-bearing districts of southern Iran, for example, the mountains are barren of vegetation and their contorted structure is most vividly shown on a mosaic. To travel over much of this country on the ground is extremely difficult, and even if it were done the detail and understanding that comes from seeing the over-all view on a mosaic would still be unobtainable. In other parts where the surface details are less pronounced, as in desert areas, the photographic mosaic is again able to provide information which is sometimes impossible to observe on the ground. On an air photograph slight changes in tone will indicate the presence of rock as opposed to sand or scrub. Areas where the water content near the surface is higher than that of the surrounding country will be shown as darker patches on the photograph. Salt deposits if not covered by sand will show as distinctive patches.

The most useful attribute of an air photograph is the ability it provides for the photo-geologist to look at an area as if with the eyes of a giant standing many thousands of feet high, and with clearer sight providing a greater sense of relief than human eyes can obtain from the same altitude.

Stereoscopic pairs of photographs show the morphology of the terrain, which can often provide a clue to the geological data. The morphology is determined by the lie of the strata, and naturally where strata that are resistant to the forces of erosion exist they will persist longer than strata which are less resistant. The vertical air photograph will show escarpments and dip slopes, and by viewing the area stereoscopically the direction and tilt of the dip can be seen. Similarly the drainage pattern can be traced, which is often a useful clue to the geological structure.

The main uses of the air photograph to the geologist can be put into three headings: firstly for preliminary office examination, secondly its use in the field, and thirdly for office check and computation. The routine followed by geologists varies according to the type of area in which they are working and often to their own experience in the past. Some prefer to undertake as complete as possible a geological interpretation of the photographs before proceeding into the field and to prepare a geological map of the area which will be a guide to the field parties. Others consider it best to take the photographs into the field direct, and to annotate the photographs with the various geological findings when in the field.

The methods of preparing accurate topographical maps suitable for geological work have been described above; for many areas however an unrectified photo-geological map is satisfactory. This is usually carried out by studying a pair of photographs stereoscopically and superimposing some non-distorting transparent material, such as Kodatrace, over one photograph and annotating on to this material the drainage pattern, alluvial beds, the main geological features and, by symbols, dip slopes and other data. A strip of photographs is interpreted in this way, information being annotated on to the Kodatrace, and then the strips of traces are compiled together and fitted into whatever basic control is available. Although this will not provide an accurate map it forms the basis of planning further geological work in the field.

It must be stressed that the interpretation that takes place in the office must always be checked by visits to the area, and must preferably be carried out by a geologist who is familiar with the area in which he is working, otherwise serious mistakes can be made.

The technique and developments that have been made in air survey can be of considerable assistance to aerial magnetometer surveys. Although there are few results to hand of oil surveys undertaken with the aerial magnetometer there is little doubt that it will be of great value in the future for making reconnaissance surveys over very large areas, particularly in difficult and inaccessible country. The advantages of carrying out a magnetic survey by air methods is that the recordings are not confused by the returns from local magnetic bodies of no depth or significance. Secondly, the survey can be carried out at great speed and in a fraction of the time that would be taken by ground methods. Thirdly, the aerial magnetometer will provide a continuous recording of the intensity of the magnetic field, whereas by ground methods recordings are only taken at intervals.

Air survey can assist aerial magnetometer surveys by providing the control to which the magnetic surveys are plotted. The area to be surveyed can be photographed from a high altitude first, and maps or photo-maps made from these photographs from which the navigation of the magnetometer survey can be planned. During the magnetometer survey flight a 35mm. camera would be used to photograph the ground, and another camera would photograph simultaneously with the ground photographs the instruments recording the height of the aircraft, the temperature, the time and the number of the ground photograph. In this way the magnetometer record is tied in with the ground photographic record, and thus the magnetometer record is related to definite geographical co-ordinates. A radar or radio aid can be used for fixing the position of the aircraft in areas where ground control is very poor or non-existent.

LE CONDIZIONI GEOLOGICO-PETROLIFERE DELLA LIBIA

By A. DESIO

Italy

ABSTRACT

Se si esamina la stratigrafia della Libia dal punto di vista petrolifero, si rileva la presenza di orizzonti forniti di caratteri favorevoli come generatori di idrocarburi. Si tratta per lo più di *sedimenti di natura argillosa che passano lateralmente a* depositi di mare poco profondo e lagunari, spesso ricchi di fossili fra cui anche pesci, con gesso e non di rado salgemma. Tali orizzonti, ricoperti per lo più da serie trasgressive, si trovano specialmente nelle serie della Creta superiore e dall'Oligocene *al Miocene* superiore. Ma questa che ho indicato è soltanto una delle condizioni necessarie e sufficienti alla formazione di giacimenti di idrocarburi. In realtà non mancano nella serie soprastante sia " rocce-magazzino," sia strati impermeabili (argillosi) di copertura.

Per quanto riguarda le condizioni tettoniche, la Libia e soprattutto la sua parte settentrionale, gode di condizioni particolarmente favorevoli in quanto il piegamento orogenico alpino è stato blando per cui ha provocato strutture tettoniche semplici sia in Tripolitania, sia in Cirenaica.

La formazione di giacimenti d'idrocarburi è però ovviamente subordinata alla coesistenza delle tre condizioni geologiche sopra indicate.

Le esplorazioni petrolifere effettuate finora hanno permesso di individuare un orizzonte miocenico lievemente impregnato nel sottosuolo della Gefara Tripolina in condizioni tettoniche, però, sfavorevoli.

GESTALT UND ERDÖLFÜHRUNG DES NORDWESTDEUTSCHEN BECKENS

By A. ROLL

Germany

ABSTRACT

Die beiden Grossschollen des nordwestdeutschen erdölführenden Beckens, die " Niedersächsische " und die " Pompeckj'sche " Scholle, vertauschten seit dem Perm zweimal—in der jungkimmerischen und in der spätsubherzynischlaramischen Phase—ihre Rollen als Hock-bzw. Tiefgebiete. Die Schichtfolgen der beiden Schollen sind daher stratigraphisch wesentlich voneinander verschieden; da zudem immer wieder örtlich wechselnde Spezialsenken und Schwellen entstanden, schwanken die Profile auch innerhalb der Grossschollen. Trotzdem sind infolge ganz bemerkenswerter, grossräumiger Ausgleichbewegungen die Gesamtmächtigkeiten der postpermischen Schichtfolge abseits der speziellen positiven Strukturen einander so ähnlich, dass die Trias-Unterkante nahezu überall grössenordnungmässig in 4000 m. Teufe liegt. Ein zweiter Ausgleichshorizont befindet sich an der Basis der weithin transgredierenden Unterkreide in durchschnittlich 1500 m. Teufe. Auf der Pompeckj'schen Scholle, welche eine grosse Zahl von Salzstöcken enthält, ist diese Regel an mehreren Stellen durchbrochen. Dort sind Jura-Tröge, z.T. kombiniert mit Tertiärtrögen, über das allgemeine Niveau hinab synsedimentär oder infolge jüngerer Tektonik eingetieft. An sie sind die isoliert liegenden Ölvorkommen geknüpft. In der Niedersächsischen Scholle dagegen, deren spärliche Salzstrukturen im wesentlichen aus durchgebrochenen Salzantiklinalen bestehen, ist die Ölführung, an Jura and Kreide gebunden, allgemein, wenn auch die Anreicherung zu Ölfeldern bisher nur im äussersten W und O nachgewiesen werden konnte.

THE TASK OF THE MICROPALAEONTOLOGIST IN PETROLEUM GEOLOGY

By HANS E. THALMANN

Venezuela

ABSTRACT

The increased application of micropalaeontology in the search for petroleum during the past twenty-five years has greatly widened the task of the palaeontologist. His primary task is to devise appropriate methods and techniques for elucidating the special stratigraphical and palaeo-ecological problems to be solved in each basin of sedimentation in which petroleum is sought. The treatment of soft and indurated rock samples, from outcrops, cores and cuttings, provides a reliable and adequate wash-residue of microfossils for the research and routine phases of faunal analysis on which stratigraphical conclusions are based. The micropalaeontologist should not restrict his attention to a single group of microfossils, but should try to determine the stratigraphical value of everything he sees under the binocular microscope. Foraminifera, Radiolaria, Ostracoda, Tintinnoidea, Algae, Flagellata, Discoasteridea, Hystrichosphaeridea, Chitinozoa, the microscopic elements of higher animals such as Spongia, Alcyonaria, Echinodermata, Pisces, Conodonts and Scolecodonts, plant spores and pollen, and a series of problematica the nature of which may be obscure, but whose presence in certain beds may be of great practical value.

Modern micropalaeontology is not limited to finding " markers " or " guide species "; populations are investigated by analytical methods, by studying the structure of their forms, their morpho-genetic tempori-spatial development and their variability. Examination of the original environment of a microfaunal assemblage provides the basis for a better understanding of facies-conditions and ecological influences, thereby permitting the reconstruction of palaeoclimatic and palaeogeographical conditions. Facies studies are important and the results can be more reliable when based on microfossils than on megafossils. The state of preservation of a fauna, sizes of components, relative abundance, ratio of species to individuals in an assemblage or of calcareous to arenaceous forms, together with petrographic examination and interpretation of the wash-residue, will lead to conclusions of great importance with regard to the facies, ecology and bionomics of a sediment.

LIST OF THE PARTS OF THE REPORT OF THE EIGHTEENTH SESSION